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Changes in Soil Organic Carbon Due to Agricultural Land Use in Alberta

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Degree for which thesis was presented — Grade pour lequel cette thèse fut présentée
Master of Science

Year this degree conferred — Année d'obtention de ce grade
Fall 1984

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CHANGES IN SOIL ORGANIC CARBON DUE TO AGRICULTURAL LAND USE IN ALBERTA

by

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A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA
FALL 1984

THE UNIVERSITY OF ALBERTA

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Abstract

Objectives of this study were to measure the extent of changes in organic carbon in cultivated as compared to native soils of all climatic zones and several cropping systems throughout Alberta; and to examine the interrelationships among observed changes in soil organic carbon content, soil properties and regional or management variables.

Profile samples were collected from cultivated and adjacent native sites on 72 farms located in the Brown, Dark Brown, Black, Dark Gray and Gray soil zones of southern and central Alberta and from the Peace River area together with data on management and site history.

Concentration losses of organic carbon in A horizons ranged from 13% to 75% while mass losses ranged between 15% and 31%. For total profiles the mass loss was between 21% and 39%. Variable gains in mass of organic carbon in A horizons occurred on 13% to 43% of the farms depending on the sampling zone.

There was no consistent decline of organic carbon with time. The change in organic carbon was related to management practices and original nature of the soil. Losses in organic carbon tended to be lower under continuous cropping than under summerfallow.

Changes in management from fallowing to more continuous cropping seem to have reversed the direction of changes in organic carbon. Existing models on organic matter dynamics

will have to be revised to accommodate changes in management.

Acknowledgements

I wish to express my grateful and sincere appreciation to the following people and institutions:

The Alberta Heritage Trust Fund for financial support of the project.

The German Academic Exchange Association (DAAD) for academic support.

My supervisor Dr. McGill for his time, constructive criticism and guidance.

My committee members Dr. Pettapiece, Dr. Robertson and Dr. Taerum for their encouragement and advice.

My field assistants Josie van Lendt and Lucy van Esbroeck for dedicated help.

All the persons who were involved in tedious sample preparation and lab analyses.

The Alberta Agriculture Plant Industry Personnel, Regional Soils Specialists and District Agriculturalists for important assistance in the project.

All the farmers for their time, cooperation and encouragement which was invaluable.

My husband Tim for his patience, understanding and moral support.

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1. Introduction

Soil organic matter is a continuum of materials varying in molecular size, reactivity and accessibility (McGill,1983). It comprises fresh litter and plant material (tops and roots) in various stages of decay; soil biomass, mostly fungi and bacteria with some small animals and insects that decompose residues; and microbial by-products of decomposition, enzymes, and material in various stages of humification (Campbell and Biederbeck, 1980).

The value of organic matter for practical agriculture flows from its functions: i)in storing and supplying essential plant nutrients, such as N,P,S and micronutrients through mineralization and cation exchange reactions (McGill and Hoyt,1977); ii)in maintaining soil structure by influencing aggregation; and thereby water infiltration, root penetration, seedling emergence, and aeration (Schroeder,1978; Scheffer and Schachtschabel,1979; Lathwell and Bouldin,1981); iii)in minimizing erosion via surface residues and aggregation (McGill,1982; McGill and Reinl,1984); and iv)possible physiological effects (McGill and Hoyt,1977).

These functions combine to influence the capability of a soil for crop production; and upon manipulation by man, its productivity.

In the 1920s and 1930s, researchers started to document a decline in organic matter on the Canadian Prairies with a concomitant decrease in yield (Shutt,1925; Caldwell et al.,1939). McGill et al. (1981) estimated that the soils of the prairies had lost 35 - 50% of their organic matter, this loss having three fundamental implications: i)loss in nutrient supplying power; ii)deterioration of soil physical properties; and iii)environmental problems relating to climate, i.e. an increase of CO_2 levels in the atmosphere.

The potential economic impact of the loss in nutrient supplying power can be estimated. For example, Beaton (1980) reported that during the period 1974 to 1978, grain harvests contained an average of 212,000 Mg of N annually in Alberta. Fertilizer addition averaged 177,000 Mg of N annually. Fertilizer N use efficiency seldom exceeds 50%. Consequently, N removal from soils averaged at least 124,000 Mg (212,000-177,000/2). At a price of 60 cents per kg this equals 14.4 million dollars annually.

Additional concerns arising from the above include soil and energy conservation, and stability and profitability of future agricultural production.

The best estimates now available suggest serious organic matter depletion problems and a trend toward continued depletion. They are, however, based upon limited data and require further testing. To this end, a Farming for the Future project supported by the Alberta Heritage Trust

Fund and titled "Conservation of Land Productivity in Alberta" was initiated.

As part of the project, this thesis has the following objectives:

1. *to measure the extent of changes in organic carbon in cultivated soils of all climatic zones and several cropping systems throughout Alberta;*

2. *to examine interrelationships among observed changes in soil organic carbon content, bulk density, moisture retention, and regional or management variables; and*

3. *to provide a broadly based data source for testing existing models which integrate our present knowledge about organic matter dynamics and which will be useful for future management decisions.*

2. Literature Review

2.1 Introduction

Scientific interest in soil organic matter has continued since the earliest scientific studies of soils. In 1836, the Russian scientist German found that cultivated soil contained less humus than virgin soil; Dokuchaev (1883) and Kostychev (1886) reported that continuous cultivation of cereals on Russian Chernozem over a long period resulted in decreased soil fertility and increased susceptibility to drought (cit. Kononova et al., 1966).

These findings suggest an important role of organic matter in crop production and have stimulated many researchers to investigate its nature, and its role in soil formation and fertility. Past efforts have concentrated on chemical and physico-chemical characterization of soil organic matter; with interest in dynamics developing mainly in the last two decades. The dynamics of organic matter require kinetic studies and descriptions of soil systems. The kinetic approach has been useful for investigating questions about the effect of cultivation on organic matter and its change with time.

2.2 Organic Matter Dynamics

Organic matter normally does not accumulate indefinitely in soil, although exceptions can occur, as, for example in permanently waterlogged soil. Usually, after a period, annual losses of organic matter through decomposition and erosion balance annual additions and thereafter the organic matter content of the soil remains at steady-state (Jenkinson,1966). This process in which losses and gains proceed simultaneously is described as turnover, and was defined as flux of organic material through the organic matter in a given sample of soil (Jenkinson,1966). Environmental factors which influence additions and removals and thereby the balance are: temperature, moisture, aeration, and pH (Allison,1973). Specific combinations of these factors determine the chemical or physical nature of organic matter formed.

Changes in the soil environment, such as breaking virgin soil or altering a system of agriculture cause changes both in the rate of addition and the rate of decomposition, and ultimately a new steady-state is reached (Jenkinson,1966; Lathwell and Bouldin,1981). The direction of change depends upon the antecedent organic matter level as well as the nature of the change in vegetation system (McGill,1982; Robertson,1983).

Man influences carbon input to land under agricultural cultivation by controlling: plant species, quantity of crop grown, proportion of time during which a crop is grown, and crop residue management. Output is influenced by controlling tillage, soil climate and erosion (McGill and Reinl,1984).

It follows that productivity of cropping systems directly influences the level of organic matter at steady-state (McGill et al.,1981). Considering the various functions of organic matter in soil, it also follows that management practices which encourage maintenance of soil organic matter should aid in: improving soil structural stability; improving infiltration; decreasing evaporation; improving drainage in fine textured soils; and fostering more extensive and deeper root systems which in turn increase moisture and nutrient availability to crops (Campbell and Biederbeck,1980).

Organic matter exists in forms with varying degrees of stability and accordingly has been conventionally divided into three components: i)an active pool with a turnover time of 1-10 years consisting mainly of litter and biomass; it is the pool most readily affected by management (McGill,1983); ii)a pool with a medium turnover time of about 60 years, termed humads by McGill and Hoyt (1977) and McGill et al.(1981), and consisting of decomposition products stabilized by adsorption and humification; and iii)a pool with a turnover time of a thousand years or more, commonly referred to as resistant organic matter.

Several mathematical and simulation models have been used to describe soil organic matter dynamics. They have been reviewed by Van Veen et al.(1981) and in Frissel and Van Veen(1981). The three component direct input model (McGill and Hoyt,1977) describes organic matter dynamics in terms of a group of independent first order reactions (Fig.1) proceeding concurrently on separate substrates. It has been used to provide many of the estimates which serve as background to the present study. Three components of different decomposability: microbes, humads and stable organic matter are thereby implicated. Instead of flowing from one component to the other, carbon flows through each component independently.

A theoretical objection to this approach is the inherent assumption that all substrates are present in the residue added. Current thinking, however, suggests that considerable transformation of one substrate into another occurs and that some of the most resistant substrates may not be stabilized or produced until some time after the addition of residues (McGill and Hoyt,1977). Restrictions in use and interpretations of model output for each individual first order reaction are: i)addition and decomposition rate must remain constant; ii)turnover time of the total soil organic component will be constant only in a steady-state situation; and iii)the model as normally used suggests continuous decline of organic matter with time unless additions are very high.

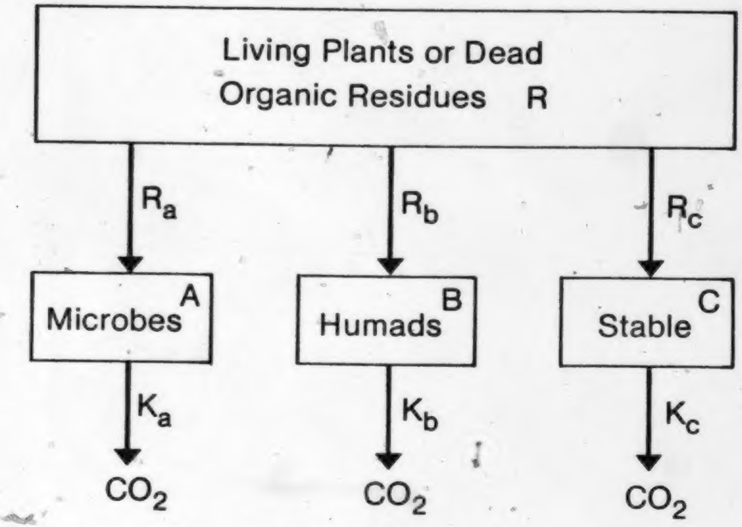

Fig.1 Three Compartment Model of Soil Organic Matter.

The change in carbon in each component is represented by the following equations:

$$dA/dt = -kaA + Ra \qquad (1)$$

$$dB/dt = -kbB + Rb \qquad (2)$$

$$dC/dt = -kcC + Rc; \ Ra+Rb+Rc=1; \text{ (McGill and Hoyt,1977).} \qquad (3)$$

Upon integrating (Sridharan,1970; Tierney,1979), the total mass of carbon at time t (Mt) is determined by both decomposition of original material(Ao,Bo,Co) at rates ka,kb,kc and by additions to each of those components at rates Ra,Rb and Rc:

$$\begin{aligned} Mt = {} & Aoe^{-kat} + Ra/ka(1-e^{-kat}) \\ & + Boe^{-kbt} + Rb/kb(1-e^{-kbt}) \\ & + Coe^{-kct} + Rc/kc(1-e^{-kct}); \text{ (McGill,1983).} \qquad (4) \end{aligned}$$

A different quantity of organic carbon at steady-state is reached for each component. Steady-state (Mss) is reached only at infinite time, i.e. e^{-kat} approaches zero, but the time at which some defined proportion (e.g. 0.9) of steady-state is reached can be calculated.

$$Mt = 0.9Mss = 0.9(Ra/ka + Rb/kb + Rc/kc) \qquad (5)$$

if Mt is increasing.

For component A:

$$0.9(Ra/ka) = Aoe^{-kat} + Ra/ka(1-e^{-kat});$$

$$0.9(Ra/ka)-(Ra/ka)(1-e^{-kat}) = Aoe^{-kat};$$

$$Ra/ka(0.9-1(1-e^{-kat}) = Aoe^{-kat};$$

$$Ra/ka(0.9-1+e^{-kat}) = Aoe^{-kat};$$

$Ra/ka(-0.1+e^{-kat}) = Aoe^{-kat}$;

$-0.1Ra/ka + (Ra/ka)e^{-kat} = Aoe^{-kat}$;

$-0.1Ra/ka = Aoe^{-kat} - (Ra/ka)e^{-kat}$;

$-0.1Ra/ka = e^{-kat}(Ao - Ra/ka)$;

$-0.1Ra/(ka(Ao-Ra/ka)) = e^{-kat}$

$-0.1Ra/(Aoka - Ra) = e^{-kat}$;

$-0.1/((Aoka/Ra) - 1) = e^{-kat}$;

$0.1/(1 -(Aoka/Ra)) = e^{-kat}$;

$\ln(0.1/(1 - (Aoka/Ra))) = -kat$

$$t = -1/ka \ln(0.1/(1-Aoka/Ra)); \qquad (6)$$

The same holds for components B and C. The time needed to reach steady-state is a function of the decay rate (ka) and of the difference between Ao and steady-state (Ra/ka). The decay rate dominates, however, because of the ln Aoka/Ra term.

Consequently component A reaches its steady-state in 5-10 years whereas component C requires several centuries. The most active component (A) does not disappear upon reducing inputs but reaches a lower steady-state and reaches it earlier than do components B or C.

Tracer studies have shown that organic materials of very different chemical constitutions are included amongst those most readily mineralized; that is with the shortest turnover time. Such isotopic work has established, however, that physically or biologically separable fractions of soil organic matter are involved to differing extents in the turnover of organic matter (Greenland,1971). Consequently there appear to be important physical and biological mechanisms which stabilize organic matter. Clay plays an important role in the former by forming organic matter-clay complexes; the latter involves microorganisms producing polysaccharides in pores of a few microns diameter enabling them to stabilize microaggregates effectively from within (Greenland,1971;Foster,1981).

Van Veen and Paul (1981) concluded from a computer simulation of organic carbon dynamics in grassland soils that the steady-state level of soil organic matter was more dependent on decay rate of the recalcitrant fraction than on that of the plant residues added to the soil. The steady-state level(Mss) is further dependent on the addition rate of plant residue (R), because Mss=R/k; a change in R causes a proportional change in Mss. Van Veen and Paul(1981) support their findings with a statement made by Jenny in 1930 (cit. Van Veen and Paul,1981) that long-term organic matter levels of soil are primarily dependent on the zonality principle: management practices of cultivated soils can alter soil organic matter levels as long as the practice is maintained. On return to natural conditions, however, levels will reapproach their long-term steady-state determined by the soil forming factors (Allison,1973). Both decomposition and addition are influenced by climatic zones because temperature and moisture control their rates. Temperate and cool humid climates favour the accumulation of organic matter, whereas hot tropical conditions enhance its decomposition (Richards,1978).

In situations where organic matter is the main source of plant nutrients, emphasis has been placed on maintenance of highly active forms of organic matter. With increased use of commercial fertilizers, as is especially the case in intensive agricultural systems of Europe, emphasis shifted toward the well-humified, resistant fractions because of their function in soil aggregation, exchange capacity, and as a source of minor nutrients (Allison,1973).

2.3 Effects of Cultivation on Organic Matter

Some studies on changes in organic matter due to cultivation have compared cultivated land to adjacent native sites, assuming that the native site represents original conditions. Changes have been reported on either a concentration or a mass basis; seldom both at once. Plot experiments have been used to investigate changes in organic matter as a function of crop rotations, fertilizer additions, and tillage intensity. Tables 1 to 5 summarize such studies with an emphasis on work from the North American Great Plains.

Comparison of cultivated and native sites showed that both concentration and mass of organic carbon in surface horizons decline after land is cultivated (Tables 1 and 2). Losses in concentration range between 14% and 80% depending on soil type, management and cultivation time (Table 1). Losses in mass range between 12% and 58%; there are some gains in mass reported for the Luvisolic and Podzolic Orders (Table 2). Newton et al.(1945) reported that the average annual loss of organic carbon from older cultivated fields was approximately half that of the newer cultivated fields; the rate of loss decreased with increased cultivation time. The same observation was made by Shutt(1925) and in other subsequent studies.

Brown et al.(1942) found significant losses also in the 15-30cm depth except for Brown Chernozemic soils.

Losses were attributed to decomposition through microbial activity and to erosion. The extent of erosion, however, is only speculative in most cases. Few studies actually measured organic matter loss due to erosion; such work was reported by Slater and Carleton(1939) and in succeeding studies conducted at the Soil Conservation Experiment Station at Clarinda, Iowa.

Changes in bulk density have been reported in association with changes in organic matter. Russel(1960) found a strong inverse relationship between bulk density and soil organic matter (r=-0.908 between bulk density and

Table 1 Changes in Concentration of Organic Carbon(OC): Comparison of Native and Cultivated Sites.

Location	Soil	Horizon/ Depth(cm)	Conc. of OC(%)		Change in Conc.(%)	YRS	Reference	Comments
			Cult.	Nat.				
Manitoba Portage la Prairie	black friable loam; sandy	0-20	8.6*	11.3	-24	20	Shutt (1925)	Data collected in 1905; Data reported as organic matter; van Bemmelem divisor of 1.724 used for conversion into %OC; *cr-sf rotations
Saskatchewan Indian Head Exp.Sta.	black heavy clay loam	0-20	6.2*	7.4	-17	22		
Indiana		Surface soil	1.0	1.9	-47	60-80	Connor (1914)	No description of soil or horizon depth;
		Subsoil	0.4	0.6	-33			
New Jersey	loam; subsoil: sandy loam	0-17	1.04^1	1.21^3	-14	8	Blair and McLean (1917)	Plot experiment started in 1908; sample date:1916; ^{1}5 yr rotation (grain and grass); ^{2}weed and grass ^{3}sampled in 1909;
			1.34^2	1.21^3	+11			
Saskatchewan Swift Current	Haverhill loam	0-30	1.46	1.99*	-27	14	Doughty et al. (1954)	*freshly broken; losses attributed to bacterial action; possibly erosion; no crops stated;
	Woodmountain loam	0-30	1.64	2.15*	-24	14		
	Woodmountain clay loam	0-30	2.41	2.91*	-17	12		

Table 1 (Continued).

Location	Soil	Horizon/ Depth(cm)	Conc. of OC(%)		Change in Conc.(%)	YRS	Reference	Comments
			Cult.	Nat.				
Kansas		0-15	1.10	1.91	-42	37	Haas et al. (1957)	average of 11 research locations on Great Plains
North Dakota		0-15 15-30 30-45	2.25 1.17 .83	3.86 1.77 1.11	-41 -34 -25	43		average of 11 farms
Quebec Ste-Foy Exp.Sta.	Gleysolic	A	3.7	6.7	-45	30	Martel and Deschenes (1976)	rotation: 1 yr cereal; 4 yrs grasses; *to bottom of B;
		Profile*	2.2	3.3	-31			
	Podzolic	Ap/L-H	3.7	22.1	-77			
		Profile*	2.7	5.6	-52			
	Podzolic	Ah-Ae	2.4	10.3	-84			
		Profile*	1.7	3.7	-54			
Alberta	Brown[1] Dark Brown[1] Black[1]	Ap/Ah	1.41 1.44 3.26	2.79 3.36 5.58	-49 -60 -42	20 65 16	Dormaar (1979)	wheat-sf-rotation; [1]Chernozemic Great Group
Alberta	Dark Brown	Ap	1.98[1] 1.53[2] 1.38[3]	3.14	-37 -51 -56	65	Dormaar and Pittman (1980)	[1]continuous wheat [2]w-w-sf [3]w-sf

Table 1 (Continued).

Location	Soil	Horizon/ Depth(cm)	Conc. of OC(%)		Change in Conc.(%)	YRS	Reference	Comments
			Cult.	Nat.				
Saskatchewan	Brown	0-15	1.1	1.9	-42	65-100*	Campbell	* estimate; cereal
	Dark Brown		1.9	3.6	-47	65-100*	and	stubble fields;
	Thin BLack		1.9	3.7	-49	65-100*	Souster	3 different textures
	Gray Luvisol		1.2	2.5	-52	40-50*	(1982)	in each Great Group:
								12 profiles
Saskatchewan	Black;¹	A	3.3	4.8	-31	60	Thiessen	¹Chernozemic
	silt loam		2.0		-58	90	et al.	No signif. changes
		B	1.5	1.6	-6	60	(1982)	in A horizon
			1.1		-31	90		thickness;
	Dark Brown;¹	A	1.7	3.2	-47	65		Db increased
	sandy loam	B	1.1	1.3	-15			with cultivation
	Dark Brown;¹	A	2.4	3.8	-37	70		
	clay to							
	heavy clay	B	2.0	2.3	-13	70		
Ontario	loamy sand	0-10	1.9	2.6	-27	35	Coote	rotation: corn;
Ottawa	sandy loam	0-10	2.6	3.1	-16		and	small grain; native:
Exp.Sta.	clay loam	0-10	1.5	2.4	-38		Ramsey	1 was pasture and
	clay	0-10	6.8	8.7	-22		(1983)	3 were strips of land
								with mature trees;
								Db higher in all depths
								in tilled sites;
								pH lower in tilled sites

Blank columns: no information available
Cult.: cultivated
Nat.: native
YRS: years of cultivation
Exp.Sta.: experimental station
Db: bulk density
w-w-sf: wheat-wheat-summerfallow
w-sf: wheat-summerfallow
cr-sf: crop-summerfallow

Table 2 Changes in Mass of Organic Carbon(OC): Comparison of Native and Cultivated Sites.

Location	Soil	Horizon/ Depth(cm)	Db ($Mg\cdot m^{-3}$)		Mass OC ($Mg\cdot ha^{-1}$)		Change in mass(%)	YRS	Reference	Comments
			Cult.	Nat.	Cult.	Nat.				
Kansas	different soil types from 13 counties	0-15					-23.8 to -51.3	50	Swanson (1915)	occasionally gain in OC in cultivated sites; speculation that wind and water erosion main factor in OM loss
Alberta and Saskatchewan	BR	0-15					-27		Caldwell et al. (1939)	32 sites; cr-sf rotations; 132 profiles; depth 105 cm; no Db stated; BL soils gained below 30 cm; losses largely attributed to bacterial action
	DB						-26			
	BL						-21			
	GR						-42			
	BR	15-30					-11			
	DB						-11			
	BL						-21			
	GR						-17			
Alberta, Saskatchewan and Manitoba	BR	0-15					-24		Brown et al. (1942)	significant losses also in subsurface except for Brown soils; 51 locations
	DB						-22			
	BL						-21			
	BLTR						-27			
	GRTR						-25			
	GR						-29			

Table 2 (Continued).

Location	Soil	Horizon/ Depth(cm)	Db (Mg·m⁻³)		Mass OC (Mg·ha⁻¹)		Change in mass(%)	YRS	Reference	Comments
			Cult.	Nat.	Cult.	Nat.				
Alberta, Saskatchewan and Manitoba	BR (11)*	0-15					-21	16	Newton et al. (1945)	85 locations; *# of locations; high average loss of Gray soils attributed to more active and less decomposed condition of surface forest litter when incorporated with the soil when first ploughed and cultivated;
	DB (19)*						-22	22		
	BL (20)*						-18	26		
	BLTR (7)*						-24	24		
	GRTR (4)*						-12	12		
	GR (11)*						-27	13		
	BR	15-30					-7			
	DB						-7			
	BL						-11			
	BLTR						-16			
	GRTR						+6			
	GR						-16			
Quebec Ste-Foy	Gleysolic	A	1.6	1.4	101	160	-37	30	Martel and Deschenes (1976)	*to bottom of B; results for profile on mass basis confirmed by Martel and Mackenzie, 1980; apparent density change in Podzols attributed to mixing of B horizon material into surface horizon;
		Profile*			119	177	-33			
	Podzolic	A	0.9	0.4	52	37	+14			
		Profile*			83	118	-30			
	Podzolic	A	1.2	0.6	49	43	+41			
		Profile*			58	90	-36			

Table 2 (Continued).

Location	Soil	Horizon/ Depth(cm)	Db ($Mg \cdot m^{-3}$) Cult.	Db ($Mg \cdot m^{-3}$) Nat.	Mass OC ($Mg \cdot ha^{-1}$) Cult.	Mass OC ($Mg \cdot ha^{-1}$) Nat.	Change in mass(%)	YRS	Reference	Comments
Saskatchewan	BL Oxbow loam	A upper*	1.15	0.9	26.4	63.6	-58	70	Voroney et el. (1981)	*slope position; 1 site; cr-sf;
		mid*	1.17	1.1	40.2	94.1	-57			
		lower*	1.21	1.1	49.2	83.3	-41			
		Profile'								'to bottom of B
		upper*			56.6	94.2	-40			
		mid*			80.7	132.1	-40			
		lower*			97.0	136.3	-29			
Alberta	BR	A			16.6	27.0	-38	70	McGill et el. (1981)	Estimate from summary data by Campbell et al.(1976), Campbell et al.(1980), Voroney et al.(1981); cropping system was assumption;
	DB				20.3	35.0	-42	70		
	BL				35.7	67.0	-47	60		
	DG				31.5	53.0	-40	50		
	GL				7.8	12.0	-35	40		

Blank columns: no information available
Cult.: cultivated; Nat.: native
Db: bulk density
YRS: years of cultivation
cr-sf: crop-summerfallow rotation
BR: Brown Chernozemic soils
DB: Dark Brown Chernozemic soils
BL: Black Chernozemic soils
BLTR: Black transition soils
GRTR: Gray transition soils
GR,GL: Gray Luvisolic soils

nitrogen). He therefore emphasized the importance of determining bulk density when soil changes over time were considered, particularly when changes were to be expressed on a mass basis.

Similarly, Davidson et al.(1967) concluded from a study on changes in organic matter and bulk density with depth under 2 different cropping systems that an increase in organic matter would cause a decrease in bulk density. For an organic carbon concentration of 1.7% the authors reported a bulk density of 1.46 $Mg \cdot m^{-3}$; for an organic carbon concentration of 0.9%, bulk density was 1.56 $Mg.m^{-3}$.

Inverse relationships between bulk density and organic carbon were further reported by Tanchandrphongs and Davidson(1970), Black(1973), Martel and Deschenes(1976), Jenkinson and Johnston(1976), Black and Siddoway(1979), Bauer and Black(1980), Voroney et al.(1981), Thiessen et al.(1982), and Coote and Ramsey(1983).

Management effects on organic matter are summarized in Tables 3 to 5. Rotations containing summerfallow were most destructive of organic matter (Shutt,1925; Doughty et al.,1954; Hill,1954; Ridley and Hedlin, 1968; Khan,1969; Ferguson and Gorby,1971; Pittman,1977; Dormaar,1979; Dormaar and Pittman,1980).

Doughty et al.(1954) demonstrated the destructiveness of summerfallowing with a pot experiment using samples of a cultivated and native clay loam and clay. Organic carbon

Table 3 Effects of Crop Rotations on Changes in Concentration of Organic Carbon (OC) in Soils.

Location	Soil	Horizon/ Depth(cm)	Conc. of OC(%) Start	Conc. of OC(%) End	Change in Conc.(%)	Rotation	YRS	Reference	Comments
Alberta Leth-bridge	sandy calc. loam	0-15	4.62*	4.87*	+ 5	10-yr rotation: 6 yrs alfalfa, 1 yr hoe crop, 3 yrs grain;	11	Shutt (1925)	*Average of 10 plots; occasionally irrigated;
		15-30	3.55*	4.03*	+14				
Ohio Exp.Sta.	acid silt loam				-3.12	cont.corn	31	Salter and Green (1933)	2 out of 5 rotations are shown;
					+3.25	corn-wheat-clover meadow			
Iowa Clarinda	Marshall clay loam	0-17.5	1.95	1.84[1]	- 6	cont.corn; corn-oats-clover	7	Slater and Carleton (1939)	Soil loss was positively linearly correlated with OM loss; [1]average of 7 plots and 2 rotations; [2]average of 5 plots and 2 rotations;
Missouri Bethany	Shelby silt loam	0-17.5	2.06	1.85[2]	-10	cont.corn; corn-wheat clover+timothy			
Iowa Clarinda	Marshall silt loam		3.39	2.86	-16	cont.corn	10	Johnston et al. (1942)	loss significant only under cont.corn
			3.37	3.46	+ 6	corn-oats-clover meadow			
			3.39	3.36	- 1	cont.corn			

Table 3 (Continued).

Location	Soil	Horizon/ Depth(cm)	Conc. of OC(%)		Change in Conc.(%)	Rotation	YRS	Reference	Comments
			Start	End					
Iowa Clarinda	Marshall silt loam	0-15	3.38	3.23	- 4	corn-oats clover meadow	1931-49	Van Bavel and Schaller (1950)	3 yr rotation did not maintain OM contrary to findings of Johnston et al. in 1942; more OM was lost than potentially possible through soil loss
			3.39	3.74	+10	alfalfa	1931-42		
			3.39	3.36	- 1	bluegrass			
			3.28	2.33	-29	cont.corn	1931-49		
Alberta Leth-bridge	Chestnut loam	0-15	3.12	2.85	-9	cont.wheat	43	Hill (1954)	yields for cont.wheat lower than in other rotations
			2.63	2.35	-11	w-sf			
			3.05	1.94	-36	w-w-sf			
			2.70	2.42	-10	sf-w-oats-sf-peas+oats-oats			
			3.23	2.16	-33	sf-c-r-sf w-w-sf-h-w			
			3.30	3.12	-5	sf-w-o-alf-alf-alf-alf-sf-c-w			
Manitoba Winnipeg	Black clayey	0-15	5.8*	4.2	-28	cont.w	37	Ridley and Hedlin (1968)	*Estimated original OC content
			5.8*	2.2	-62	w-sf			
Western Austra-lia	Coolup sand	0-12.5	0.77*	2.0	+160	cont.pasture	33	Barrow (1969)	*native; Db not changed
			0.84*	2.2	+162	cont.pasture	40		

Table 3 (Continued).

Location	Soil	Horizon/ Depth(cm)	Conc. of OC(%) Start	Conc. of OC(%) End	Change in Conc.(%)	Rotation	YRS	Reference	Comments
Alberta Breton	Gray Luvisol	Ap		1.4		grain-legume	39	Khan (1969)	
				1.1		w-sf			
				1.7		grain-leg.+man.			
				1.6		w-sf+man.			
Alberta Leth-bridge	Dark Brown	0-15			-14*		20	Pittman (1977)	*average of 7 rotations
		0-30			-24*				
		0-15	1.68	1.36	-19	w-w-sf			
			1.69	1.49	-12	cont.wheat			
			1.70	1.49	-12	w-w-sf+man.			
			1.71	1.50	-12	sf-w-w+ 3 yrs grass +alf.			
Manitoba Brandon	Cherno-zemic Order	0-15	0.232*	0.178*	-23	cont.sf	12	Ferguson and Gorby (1971)	*N as indicator of OC
			0.245*	0.206*	-16	alfalfa	8		

Blank column: information not available
Db: bulk density
YRS: rotation length
alf: alfalfa
c: corn
cont.: continuous
h: hay
man.: manure
o: oats
r: rye
sf: summerfallow
w: wheat
calc.: calcareous

Table 4 Effects of Additions of Organic Residue and Inorganic Fertilizer on Concentration of Organic Carbon(OC) in Soil.

Location	Soil	Horizon/ Depth(cm)	Conc. of OC(%)		Db (Mg·m^{-3})		Residue/ Fertilizer	YRS	Reference	Comments
			Start	End	Start	End				
England Rothhamsted	clay			0.50		1.19	fallow		Williams and Cooke (1961)	
				1.87		1.04	14t man./ac	85		
				2.36		0.94	grass	100		
Ottawa Exp.Sta.	clay	0-15	2.91	2.44			control	20	Sowden and Atkinson (1968)	annual additions; equivalent of 9kg of dry OM to clay plot(8m^2) and of 4.5kg to sand plot(4m^2); pulverized and incorporated into top 15 cm; rye as green manure;
			2.96	2.49			rye			
			2.91	2.88			straw			
			2.97	2.81			alfalfa			
			2.81	3.57			peat			
			2.79	4.37			muck			
			2.83	3.05			manure			
	sand	0-15	1.37	1.23			control			
			1.06	1.26			rye			
			1.33	1.70			straw			
			1.26	1.32			alfalfa			
			1.27	1.29			peat			
			1.11	2.61			muck			
			1.11	1.77			manure			
Montana Culbertson	sandy loam	0-30	0.01	0.15	1.38*	1.27*	wheat stubble mulch	8	Black (1973)	cr-f-rotation; addition of 0-6.7t/ha; *0-9.6cm;

Table 4 (Continued).

Location	Soil	Horizon/ Depth(cm)	Conc. of OC(%)		Db ($Mg \cdot m^{-3}$)		Residue/ Fertilizer	YRS	Reference	Comments
			Start	End	Start	End				
England		0-23	0.9	0.9	1.9	1.9	unmanured	124	Jenkinson	Classic
Rothham-			1.1	1.1	1.5	1.5	PK		and	Hoosfield
sted			0.7	1.0	1.5	1.6	NPK	1852-	Johnston	continuous
										barley
			2.4	3.1	1.4	1.3	FYM	1976	(1976)	experiment;
				1.5	1.5	1.5	FYM(1852-1871)			annual treatment
Montana	sandy	0-7.6	1.8	2.2	1.38	1.27	wheat*	8	Black	*added
	loam	7.6-15.2	1.3	1.7	1.63	1.55	straw		and	at different
		15.2-30.2	1.1	1.3					Siddoway	rates
									(1979)	(0-6.7t/ha)
										during fallow of
										w-f-rotation
Cali-	calc.	0-30	0.9	1.7			180-360-0-0*	7	Meek	$Mg\ ha^{-1}$of
fornia	Holt						180-180-180-0*		et al.	manure in
	ville		0.9	1.8			180-180-180-0*		(1980)	71-74,respectively;
	soil									*$Mg \cdot ha^{-1}$; annual
										sampling;
										irrigated;

Blank column: no information available
Db: bulk density
YRS: years under treatment
PK: phosphorus potassium
NPK: nitrogen phosphorus potassium
FYM: Farm yard manure
calc.: calcareous
cr-f: crop-fallow
man.: manure
w-f: wheat-fallow

Table 5 . Effect of Tillage Intensity on Concentration of Organic Carbon(OC) in Soil.

Location	Soil	Horizon/ Depth(cm)	Concentration of OC(%)			Db ($Mg \cdot m^{-3}$)		YRS	Reference
			NT	STM	CT	STM	CT		
Oklahoma	silt	0-10		0.75	0.73			11	Tanchandrphongs
Exp.Sta.	loam	10-20		0.82	0.73				and
		20-30		0.80	0.73	1.42	1.48		Davidson
		30-40		0.79	0.71	1.42	1.48		(1970)
Kentucky	silt loam	0-7.5	1.55[1]					9	Doran
Minnesota	clay loam		1.07					9	(1980)
West Virginia	silt loam		1.20					5	
Nebraska	silt loam/ loam		1.10					3	
Nebraska	loam		1.50					9	
Nebraska	silt loam		1.25					10	
Oregon	silt loam		1.10					9	
Kentucky	as	7.5-15	0.81						
Minnesota	before		1.00						
West Virginia			0.97						
Nebraska			1.05						
Nebraska			1.00						
Nebraska			0.98						
Oregon			0.88						
Kentucky	as	15-30	0.90						
Minnesota	before		0.89						
West Virginia			1.02						
Nebraska			0.97						
Nebraska			0.98						
Nebraska			0.93						
Oregon			0.82						

[1]: Ratio of no till: conventional till(%OC).
Ratio >1: increase with no till
Ratio <1: increase with conventional till

Table 5 (Continued).

Location	Soil	Horizon/ Depth(cm)	Concentration of OC(%)			Db (Mg·m⁻³)		YRS	Reference
			NT	STM	CT	STM	CT		
North Dakota	sandy	0-46		1.14	0.79	1.24	1.24	25	Bauer and Black (1981)
	medium			1.33	1.36	1.09	1.09		
	fine			2.03	1.79	1.03	1.03		
Ohio	silty loam	0-23	1.25	1.08	1.05[1]			19	Dick (1983)
	silty clay loam		2.30	2.02	2.00			18	

[1] Values for native comparison are 1.4 and 2.3, respectively

Blank column: no information available
Db: bulk density
CT: conventional till
Exp.Sta.: experimental station
NT: no till
STM: stubble mulch
YRS: years of treatment

content was measured at the beginning and end of 5 years. Losses varied from 18.6% for the cultivated Sceptre clay (1.94% start; 1.58% end), 19.9% for the cultivated Woodmountain clay loam (2.73% start; 2.26% end) to 21% for the virgin clay (2.73% start; 2.15% end) and 24% for the virgin clay loam (3.8% start; 2.88% end). The higher losses in the virgin soils were attributed to a higher proportion of more easily decomposable material.

Ridley and Hedlin(1968) implied that rapid decline of organic matter in frequently fallowed land was due to higher frequency of tillage operations. Tillage was considered to disrupt aggregates and expose new areas to microorganisms thus promoting more rapid oxidation of organic carbon as suggested by Rovira and Graecen(1957).

More intensive cropping slowed down the rate of organic matter decline which was attributed to greater addition of residue in the form of roots because aboveground residues had been removed (Ridley and Hedlin,1968). Roots are intimately mixed with the soil at all times. Their excretions and residues provide substrate for microorganisms (Allison,1973). Extracellular microbial products participate in stabilization of microaggregates and slow decomposition by physical protection (Greenland,1971).

Grasses and legumes decreased losses in organic matter (Blair and McLean,1917; Shutt,1925; Salter and Green,1933;

Johnston et al.,1942; Van Bavel and Schaller,1950; Hill,1954; Khan,1969; Sowden and Atkinson,1968) through high below ground primary production (McGill and Hoyt,1977).

Jenkinson(1977) monitored the rate of carbon loss over 10 years from C^{14}-labelled plant material incubated in soils under fallow and grass. Decomposition under growing grass was considerably slower than under bare fallow. After 5 years there was 47% more of the originally added material under grass than under fallow. The protection given by the grass ended as soon as it was removed leading to a decomposition rate of the labelled material which was twice as high as under bare fallow and after 10 years both soils contained approximately the same amount of added material. The slower decomposition rate under grass could not be explained by recycling of C^{14} through photosynthetic fixation, translocation, and return to the soil because C^{14} content of the grass was too low to be detected.

The rapid accumulation of soil organic matter usually observed when arable land is put under grass is attributed to: i)increased annual return of carbonaceous material; and ii)decreased rate of decomposition under grass (Jenkinson,1977). The latter was ascribed to limiting N supply (Huntjens and Albers,1978).

Row crops appeared to be more destructive to soil organic matter than cereal crops (Salter and Green,1933; Johnston et al.,1942; Coote and Ramsey,1983). Row crops require frequent tillage for reducing weed competition; and soil is left bare during a longer portion of the vegetation period due to slow initial growth of row crops (Geisler,1980).

Additions of straw and manure may increase organic matter (Table 4). Manure is a source of the major plant nutrients N,P,K (Allison,1973) and like other residues may ameliorate soil conditions for plant growth thus enhancing primary productivity (McGill and Hoyt,1977).

Application of mineral N and P seems to be conducive to preventing organic matter losses by increasing production and therefore return of residues, mainly of roots (Jenkinson and Johnston,1976).

Zero till, minimum till and stubble mulching lowered the rate of organic matter loss as opposed to conventional tillage practices (Table 5). Aeration, oxidation and erosion are reduced because little physical disruption of aggregates occurs. Doran's(1980) data indicate that the positive effect of zero tillage might be mainly present in surface horizons. There may be a greater loss in subsurface horizons under zero tillage than under conventional tillage. The author attributed this to placement of crop residues at depth with ploughing under conventional tillage.

2.4 Conclusions

Magnitude and direction of change in organic matter are related to the balance between original amount of organic matter and kind of management introduced.

The rate of organic matter loss tends to be highest in the initial years of cultivation; thereafter losses continue at lower rates. Losses in mass tend to be lower than losses in concentration which has been reported to be due to an inverse relationship between organic carbon and bulk density.

Losses occur if the removal rate exceeds the addition rate. Frequent tillage operations and summerfallowing increase removal rates directly by enhancing decomposition rates; indirectly by making the soil more susceptible to erosion. Decomposition and erosion are linked by a positive feedback mechanism.

Rotational studies showed that organic matter may increase if legumes and grasses are grown; and that it decreases most rapidly if summerfallowing is practiced. Continuous cropping slows organic matter losses mainly by increased addition of root residues. Additions of organic residues increase the addition rate and may increase organic matter if the removal rate remains constant. Zero till is considered to reduce decay rates and thus cause organic matter levels to rise. Data of Doran(1980) indicate that this might be a redistribution effect rather than actual accumulation of organic matter.

It follows from the above that a change in management may cause organic matter losses to cease or change direction if the introduced management practice either lowers removal rate, e.g. by reduced tillage intensity, or increases addition rate.

Very few such measurements have been made on farm fields so far. Mathematical treatments of organic matter dynamics under the influence of cultivation are based on the assumption that management remains constant. Therefore, in their present form, they are inadequate to describe systems where changes in management alter organic matter dynamics.

3. Materials and Methods

3.1 Field Work

Soil samples were collected from cultivated fields and adjacent native sites on 72 farms located in various climatic and soil zones of Alberta (Fig.2). Six major sampling zones, from south to north, were delineated (Fig.3):

1.Brown (BR)
2.Dark Brown (DB)
3.Black (BL)
4.Dark Gray (DG)
5.Gray Luvisol (GL) soil zones and the
6.Peace River area (PR) which contains soils of the Solod, Solodized Solonetz, Gray Luvisol and Dark Gray Great Groups.

3.1.1 Site Selection

Farms were selected with the help of Alberta Agriculture through District Agriculturalists, Regional Plant Industry personnel and Regional Soils Specialists. They contacted and provided names of farmers who were willing to cooperate and who possessed possible sample sites.

The following criteria were applied in finally selecting sampling sites:

1. location of a cultivated field adjacent to an undisturbed native site accessible to a coring truck;

7

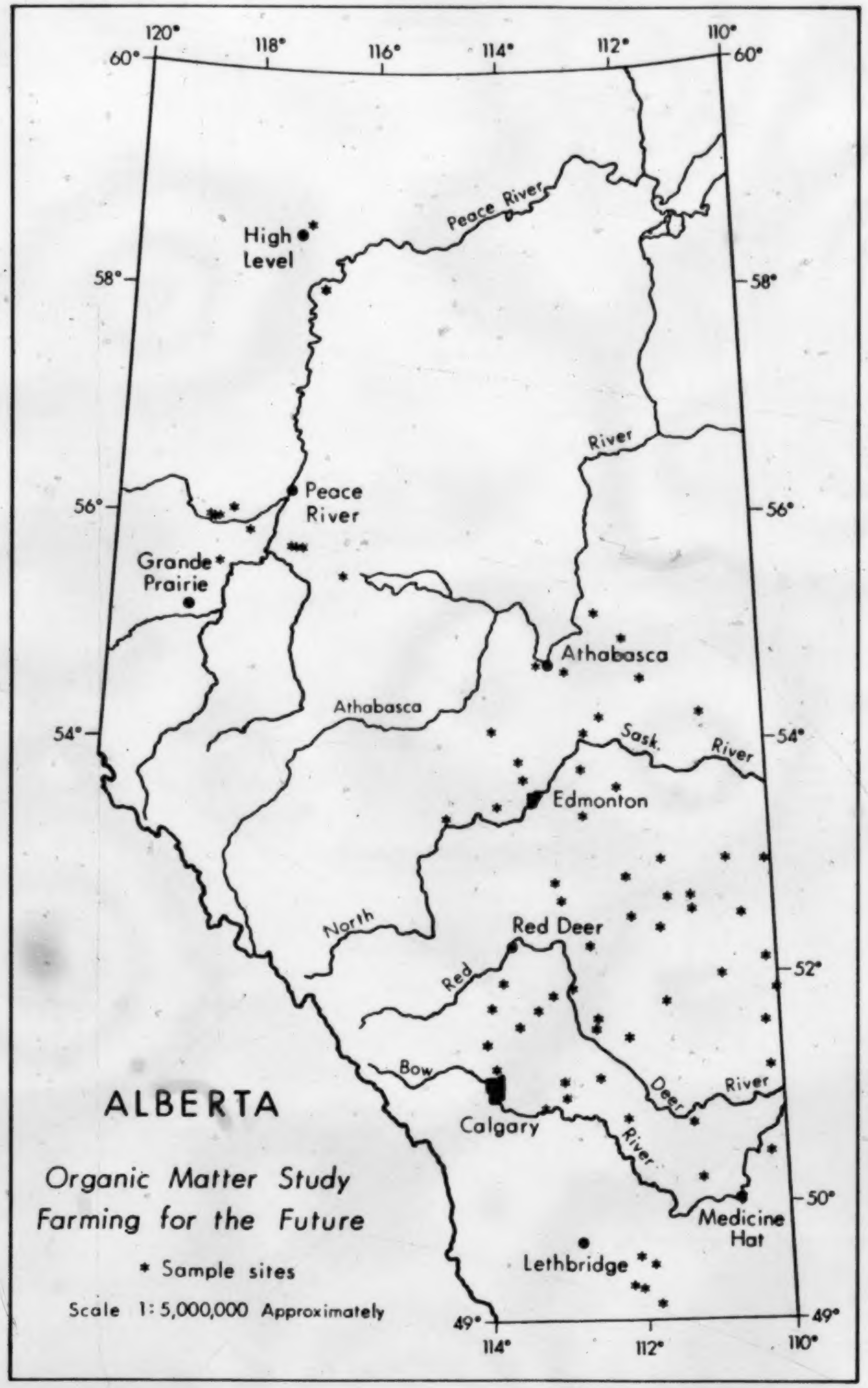

Fig.2 Location of Sample Sites in Alberta.
Fig.3 Location of Sampling Zones in Alberta.

2. presence of soils of the same origin on both sites and therefore of the same parent material, microclimate, topography, drainage, and native vegetation;
3. availability of field history and good management records;
4. absence of effects due to fencelines, wind-drifts, and former threshing piles.

The distribution of sites between sampling zones is uneven due to different farming density. The distribution of sites within sampling zones was determined by cooperation and adequate sampling conditions. In areas of high site density, the site numbers had to be reduced because of time and financial restrictions, in which case maximization of the geographic distribution was the basis for selection.

3.1.2 Soil Sampling

At each farm, 8 profile pairs were sampled with a hydraulic soil corer along a transect as depicted in Fig.4. The diameter of the coring tube was 4.5 cm, and its maximum depth was one meter. Sampling was to the C horizon wherever possible. Problems arose on rocky soil as penetration to sufficient depth was difficult or when subsurface material consisted of a large proportion of clay which caused compaction. Apparent compaction from the surface of the soil to the top of the soil in the coring tube was measured for each core.

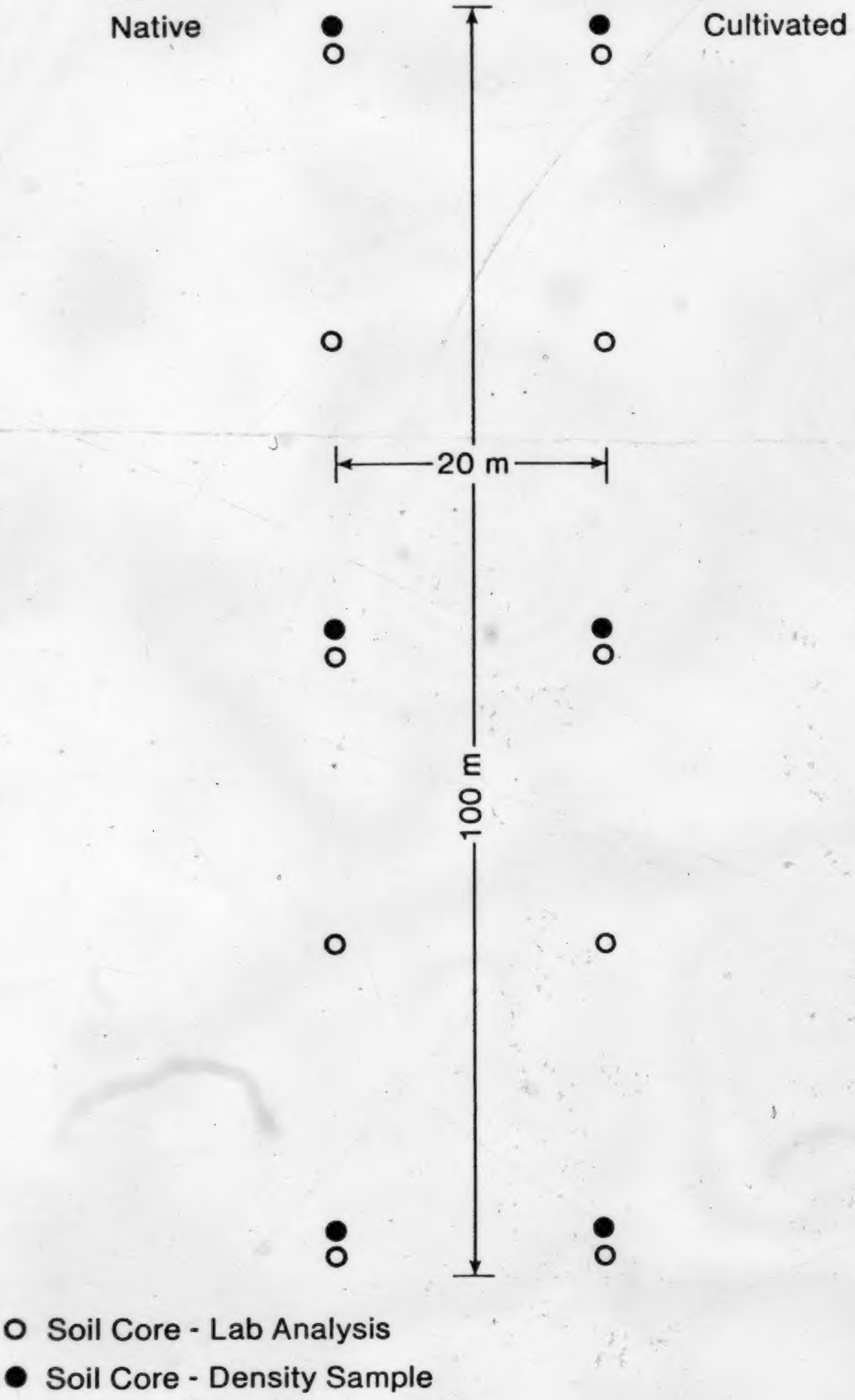

Fig.4 Schematic Diagram of the Method of Soil Sampling.

For five of the profile pairs, horizons were delineated, horizon thickness measured, texture of the parent material determined and each horizon sample stored separately for analyses.

At 15 to 30 cm away from cores #1,#3, and #5, an additional core was taken for the purpose of determining mass and apparent bulk density for each horizon. Horizons were therefore left undisturbed; compaction and horizon depth were measured and each horizon sample stored separately.

3.1.3 Field History

A questionnaire (Appendix I) was provided to each farmer and, whenever possible, completed on site with the farmer. The information derived consists of the total time of cultivation, crop rotations, management practices, and yields, aiming at the assessment of input-output relationships for the respective soil-cropping system.

Questionnaires which could not be answered in the field were subsequently mailed in. Some questionnaires were not returned and a complete statistical analysis could not be performed in those cases.

3.2 Lab Procedures

3.2.1 Sample Preparation

Samples were air-dried and their mass determined on a top-loading balance. Samples for lab analysis were ground to 2 mm. A subsample was ground in a Siebtechnik laboratory disc mill (Model TS100A) to 100 mesh which is equivalent to a particle size of 0.149 mm or very fine sand according to the Wentworth size class (Quaternary Research Group, 1979).

For each sample set the dry Munsell color of the A-horizon was recorded for classification purposes.

3.2.2 Apparent Bulk Density

Bulk density is the ratio of mass to macroscopic volume of soil particles plus pore spaces in a sample (Black et al., 1965, Vol. 1). The mass of the samples taken for bulk density measurement was therefore divided by the product of horizon depth and area of the coring tube (15.9 cm^2). Compaction measured was minor except for a few C horizons and was not included in the calculation of bulk density. Because of this, together with the fact that air-dry instead of oven-dry mass was used in the calculation, bulk density will be referred to as apparent bulk density.

3.2.3 Soil pH

Soil pH was measured in water for the 2 mm samples as described in McKeague (1978;p67-68). The suspension had a soil:water ratio of 1:2.5; this value was adopted in 1930 by the Soil Reaction Committee of the International Society of Soil Science (Black et al.,1965).

Measurements were conducted potentiometrically with a Fisher Acumet pH meter Model 630. The instrument was standardized in buffer solutions at pH 4 and pH 7. The glass electrode was immersed into the partly settled solution, the calomel electrode into the supernatant to reduce errors caused by the liquid junction potential in clay and soil suspensions (Black et al.,1965). Results were recorded to one decimal.

3.2.4 Inorganic Carbon

Inorganic carbon was determined for 2 mm materials by acid-neutralization in boiled samples (Black et al.,1965;p1387-1388) whenever the pH of a sample was equal to or greater than 7 which was the case for 800 samples. Plotting of the carbonate values versus the pH measurements (Fig.5) indicates that a pH of 7 is acceptable as a cut-off point for carbonate determination for purposes of the present study.

The recommended molarity of the NaOH (0.25 M) was inconvenient for samples with low carbonate content because of the high amount of base needed to neutralize the acid

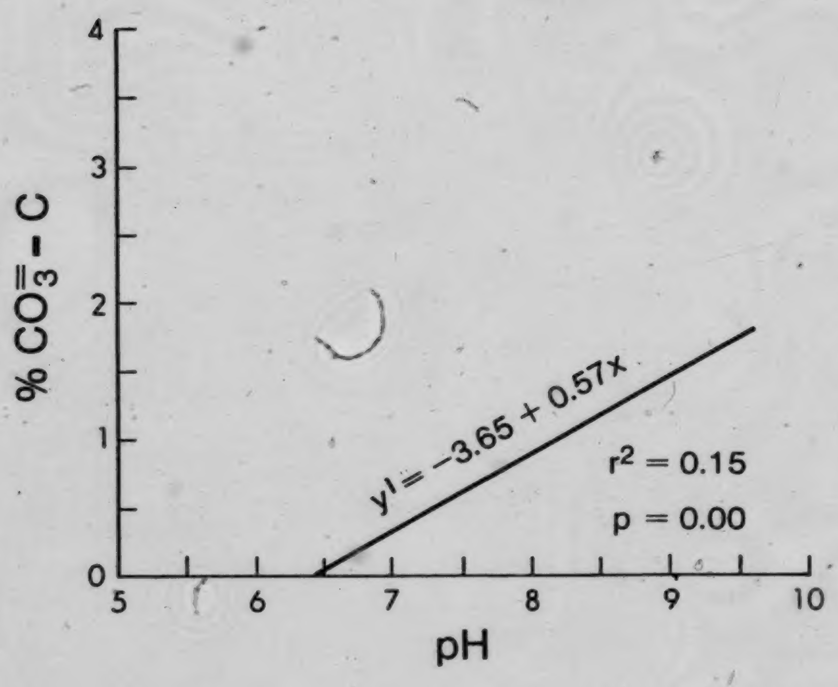

Fig.5 Relationship Between Inorganic Carbon(%) and pH of Soil Samples from A, B, and C Horizons of Soils throughout Alberta (n=800).

(HCl). The concentration of NaOH was therefore raised to 0.5 M. The actual concentration of base was determined daily by titrating a known volume of base with standard HCl, in order to overcome changes in NaOH concentration caused by absorption of H_2O and CO_2. If samples showed violent frothing with HCl due to high carbonate content, further measured amounts of HCl were added until no sign of a reaction occurred.

Visual recognition of the phenolphthalein endpoint was difficult due to the often yellow-brown color of the filtrates which were collected after the soil-acid mixture had been boiled and cooled. The method was therefore changed by using a potentiometric titration to pH 8.2 controlled automatically by a Radiometer Titrator Type TTT IIb operated according to the manufacturer's manual. The two methods yielded the same results when compared on the same samples.

A blank was run with each set of samples. The coefficient of variation of an internal standard soil sample was 2.26%.

3.2.5 Total Carbon

Total carbon was determined by oxidation at 1300°C with a resistance furnace (Leco Carbon Determinator CR12, Model 780-000) in an O_2 stream followed by infra-red CO_2 detection as described in the manufacturer's manual. Mass of the sample (<100 mesh size) varied between 0.1g and 0.3g depending on the expected carbon content. Previously dried

$CaCO_3$(12%) stored in a dessicator was used for calibration. The coefficient of variation of an internal standard soil sample was 3.5%. Results were recorded to two decimals.

3.2.6 Organic Carbon

Organic carbon was calculated by subtracting % inorganic carbon from % total carbon and reported as such rather than converted to organic matter content because considerable variation exists in the C:organic matter ratio among different soils, and also among horizons of the same soil (Black et al.,1965;Page et al.,1982).

3.2.7 Moisture Retention

Moisture retention at -33kPa and -1500kPa was determined for disturbed 2 mm samples of A-horizons. A Pressure Plate Extractor CAT.#1600, Soil Moisture Equipment Co.,Santa Barbara, California was used for -33kPa and a Ceramic Plate Extractor CAT.#1500, Soil Moisture Equipment Co.,Santa Barbara, California for -1500kPa, respectively.

The sample size was 25g, retainer rings had a diameter of 5cm. A control soil was run with each sample set. The coefficient of variation of the control at -33kPa was 11.7% and 18.4% at -1500kPa.

3.3 Data Management

Field, lab and questionnaire data were coded and recorded on coding sheets prior to keypunching, entry into three MTS files, and further preparation for statistical analysis. The contents of the files were respectively:
i) farm location and pedological site description;
ii) management and input-output data in terms of yields and fertilizer additions; and iii) chemical and physical analyses data. Data were stored on tape. The codebooks are listed in Appendix I. Statistical analyses used SPSS and SPSSx statistical packages.

4. Changes in Soil Properties

4.1 Introduction

The objective of this section is to document changes in soil properties due to cultivation. The following soil characteristics are compared on cultivated and native samples: concentration and mass of organic carbon and their respective changes; horizon thickness; pH; apparent bulk density; moisture retention at -33 and -1500kPa; and available moisture capacity. The change in organic carbon when calculated at the profile, farm and sampling zone level is also presented.

4.2 Methods of Statistical Analysis

Data presented and discussed in this section were obtained from lab analyses and field measurements. Using SPSSx subprogram T-Test the null hypotheses of no difference between the following means have been tested:

1. Concentration of organic carbon in cultivated and native A horizons.
2. Mass of organic carbon in cultivated and native A horizons.
3. Mass of organic carbon in cultivated and native profiles(to bottom of B horizon).
4. Change in organic carbon on a concentration and mass basis.
5. Depth of cultivated and native A horizons.

6. Apparent bulk density of cultivated and native A horizons.
7. The pH of cultivated and native A horizons.
8. Distribution of organic carbon, apparent bulk density, and pH with depth in cultivated and native profiles.
9. Moisture retention at -33 and -1500kPa, and available moisture capacity in cultivated and native A horizons.

At the farm level t-tests were based on the assumption that samples were independent. Pooled or separate sample variances were used depending on whether samples came from populations with equal or unequal variances determined by an F-Test(Nie et al.,1975,p.270).

A paired t-test was used for testing null hypotheses on a soil zone level. Because of the influence of soil forming factors it was assumed that means of cultivated and native sites per farm would be more closely related to each other than would be means of cultivated and native sites of all farms within a zone. Thus, small but consistent differences were more likely to become statistically significant.

Highly significant, and significant are used throughout to designate statistical significance at the 1 % and 5 % level,respectively.

Results are presented for the sampling zone level only. Summary results by farm are included in Appendix II. In each of the Brown(BR), Dark Brown(DB), Black(BL), Dark Gray(DG), Gray Luvisolic(GL) and Peace River(PR) sampling zones 14, 16, 15, 2, 7, and 12 farms were analyzed statistically. This amounts to 70, 80, 75, 10, 35 and 60 profiles at each of the cultivated and native sites in the above sampling zones, respectively.

4.3 Results

Content of organic carbon(OC) can be expressed as concentration (g/100g soil) or mass ($Mg \cdot ha^{-1}$). The mass of organic carbon per hectare over a given depth, e.g. depth of the A horizon, is obtained by multiplying the concentration by bulk density and horizon depth, accounting for changes in units. Concentration indicates the amount of organic carbon associated with mineral soil constituents which is of interest with regard to soil physical properties such as aggregation; it has a qualitative connotation. Mass is pertinent in terms of quantitative aspects for assessing nutrient release, release of CO_2 to the atmosphere, or organic carbon lost by erosion.

4.3.1 Calculation of Changes in Organic Carbon

The possible range of results obtained when calculating changes in organic carbon at different levels of hierarchy such as profile, farm, and soil zone is illustrated in Fig.6. An example calculation for the GL zone is presented in AppendixII.5 (p.158). The presence of a denominator in

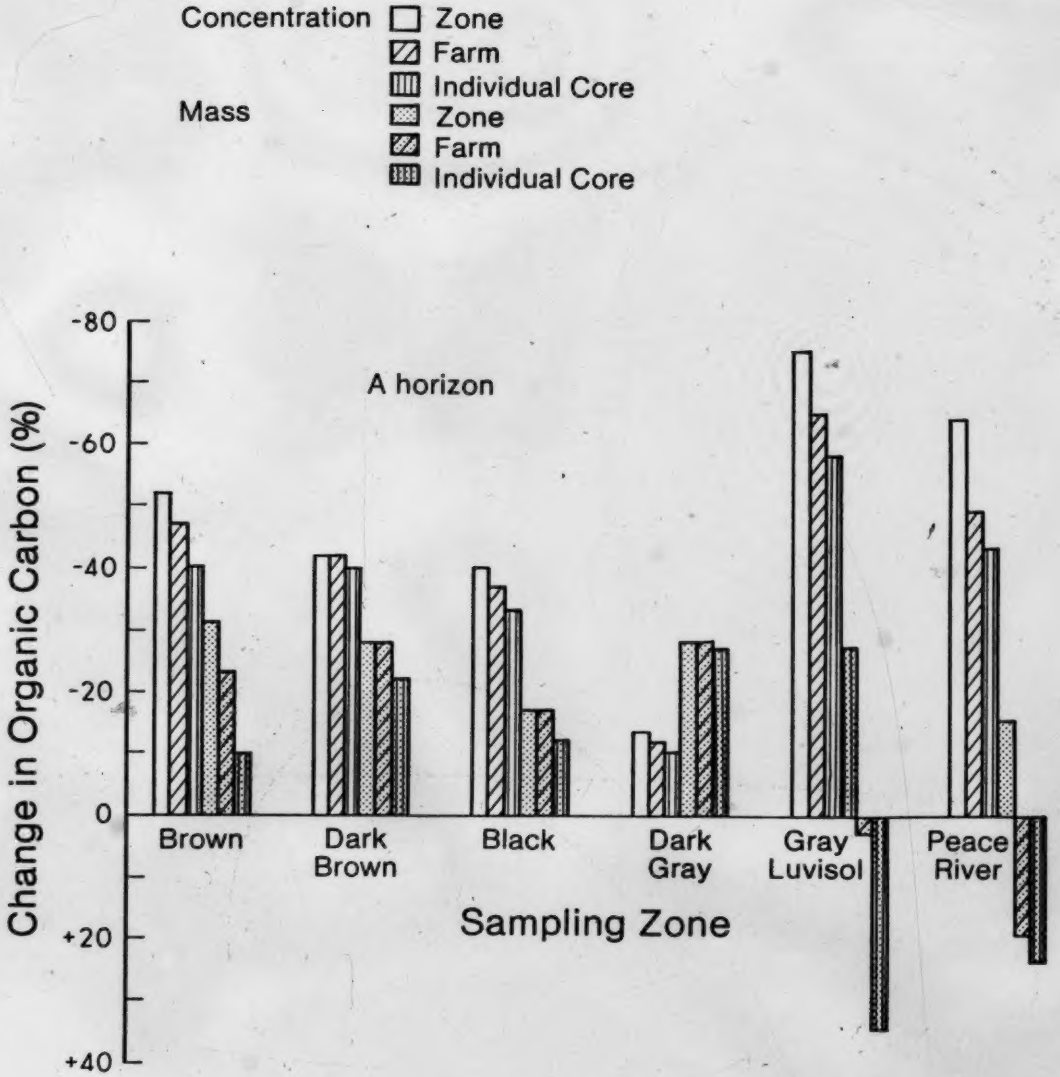

Fig.6 Change in Organic Carbon Based on Calculation at Different Levels of Hierarchy.

the equation for organic carbon change[1] can skew the results depending on the level of hierarchy and variability in the denominator:

1. Changes can be calculated directly from the difference between the means of organic carbon at the sampling zone level. These means are derived from the average organic carbon content of cultivated and native sites at the farm level. This method does not provide for calculation of standard deviations of the change.
2. Changes can be calculated at the farm level and averaged for the soil zone level.
3. Changes can be calculated on the profile level and averaged for the farm and soil zone level.

Normally changes are most negative with the first method and least negative with the third. Mass changes at the profile and farm levels are most sensitive to variability in horizon thickness and therefore mass of soil which influences mass of organic carbon. This is especially the case for Luvisols because mixing of the thin LFH with subsurface horizons markedly influences mass of soil in the Ap horizon.

The first method was used for calculating the results presented. It seems to be the method frequently used in the literature. In many cases, however, a description of the method used is missing.

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[1] % change=((B-A)/A)100; where A is original carbon content and B present carbon content; negative sign means loss, positive sign means gain

4.3.2 Concentration of Organic Carbon in Cultivated and Native A Horizons

Concentration of organic carbon in native surface horizons was highest in the Gray Luvisolic zone(9.3%) which contains some LFH horizons (Fig. 7). Native A horizons of the Peace River area include some Luvisols accounting for the high concentration of organic carbon(8.3%); eliminating the Luvisols in this zone lowers the average concentration below that for the Black soil zone. In the Chernozemic Great Groups there was an expected decline in concentration of organic carbon in the native A horizons with increasing moisture deficit from north to south with 7.0% for the Black, 4.7% for the Dark Brown and 2.9% for the Brown soil zone. Average concentration for the Dark Gray soils was 3.3%.

Upon cultivation the concentration in organic carbon decreased with the greatest absolute difference in soils originally highest in organic carbon. In cultivated A horizons the highest concentration of organic carbon was present in the Black Chernozemic soils(4.2%), followed by the Dark Gray(3.3%), Peace River(3.0%), Dark Brown(2.7%), Gray Luvisolic(2.3%) and the Brown soils(1.4%).

Differences in concentration of organic carbon between cultivated and native A horizons were highly significant except for the Dark Gray soils which might have resulted from the low number of farms sampled in this zone.

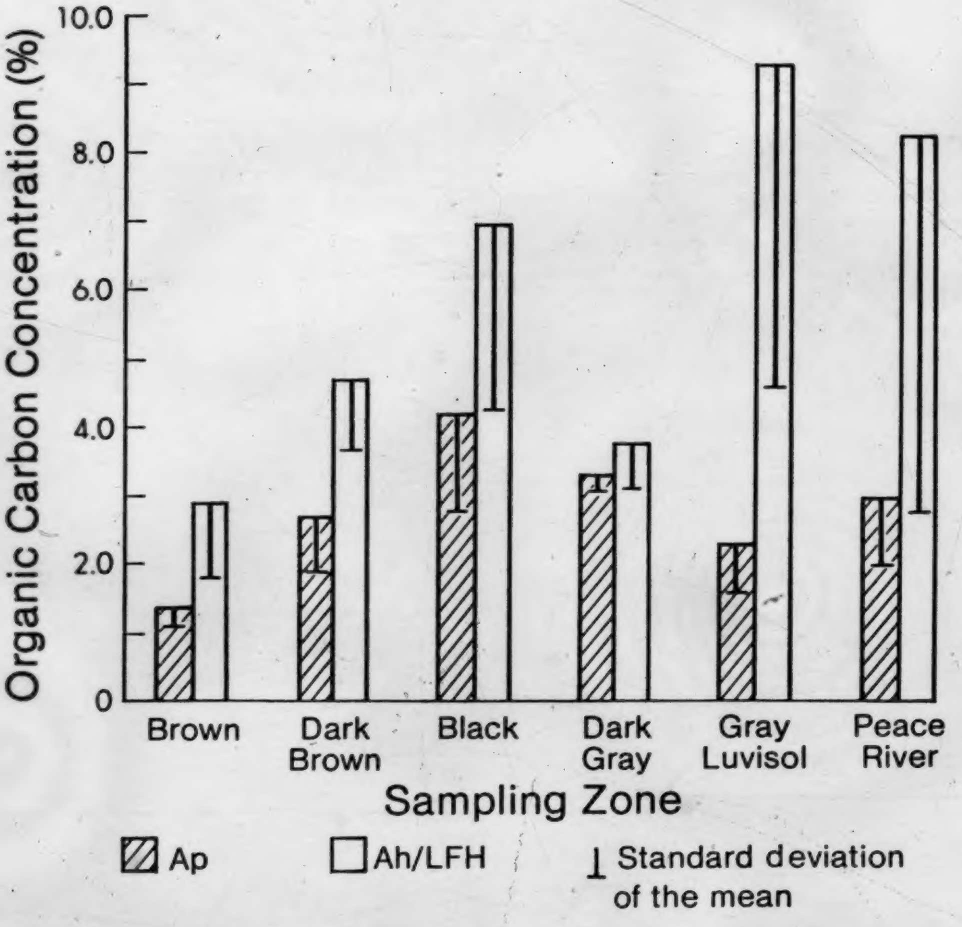

Fig.7 Average Concentration of Organic Carbon in Cultivated and Native A and/or LFH Horizons of Soils in Alberta.

4.3.3 Mass of Organic Carbon in Cultivated and Native A Horizons and Profiles

Mass of organic carbon in native A horizons was highest in the Black soils followed by the DG, PR, GL, DB and BR soils (Fig.8); in the native profiles, mass follows the same distribution except that PR and DG soils exchange position. The mass of OC in the native A horizon constitutes 47%, 58%, 61%, 69%, 63% and 55% of the total mass of organic carbon in the profile of the BR, DB, BL, DG, GL and PR soils.

Mass in cultivated A horizons and profiles was lower than in native samples. Apart from the DB and DG soils, mass of organic carbon in the A horizon constitutes a higher proportion of the total mass in the profile than in the native samples. This is most notable for the Gray Luvisols. Cultivated A horizons contain 60%, 56%, 65%, 64%, 76% and 63% of the total mass of organic carbon in the profile.

Differences in mass of organic carbon between cultivated and native samples were highly significant for A horizons of the BR and DB soils, and for the profiles of the BR, DB and BL soils; differences in mass were significant for the DG and GL profiles. None of the differences for A horizons or profiles were statistically significant for the Peace River soils.

At the individual farm level some positive changes occurred: 21%,13%, 33%,43% and 42% of the sites in the BR, DB, BL, GL and PR sampling zone had a gain in mass of organic carbon in the A horizon. Continuous cropping was

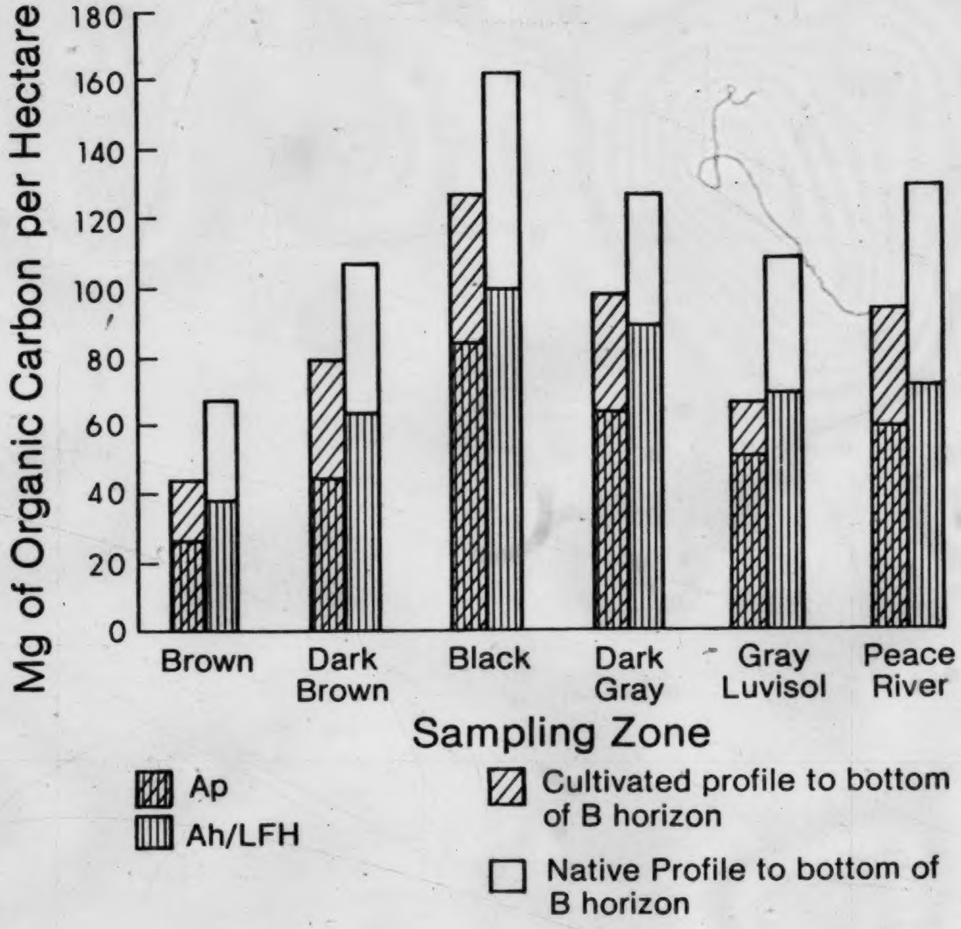

Fig.8 Average Mass of Organic Carbon in Cultivated and Native A and/or LFH Horizons and Profiles of Soils in Alberta.

practiced on 34%,100%,60%,34% and 60% of these sites in the above order of the sampling zones. Lay farming was practiced on 20% in the Black and 33% in the Gray Luvisolic zone. The remainder is constituted by fallow rotations.

A mass gain in the profile occurred on 14%,13%,14% and 33% of the sites in the BR, BL, GL and PR zones. Continuously cropped sites constituted 50% of these sites in the BR, BL and PR zones; 50% of these sites in the GL zone were under lay farming; the remaining percentages were under fallow rotations.

4.3.4 Changes in Concentration and Mass of Organic Carbon in A Horizons

The change in mass was less than in concentration (Fig.9) except for the DG soils where it was highly significantly greater. Differences were highly significant for the BR, DB and GL soils; they were significant for the BL and PR soils. Numerical values are listed in Appendix II.1 to II.6.

4.3.5 Average Thickness of Cultivated and Native A Horizons

Apart from the Dark Gray Chernozemic soils, cultivated A horizons were thicker than native A horizons (Fig.10) suggesting mixing of subsurface horizon material into the A horizon. This trend was especially apparent for the Gray Luvisolic and Peace River soils. Due to great variability in horizon depths, however, none of the differences in horizon

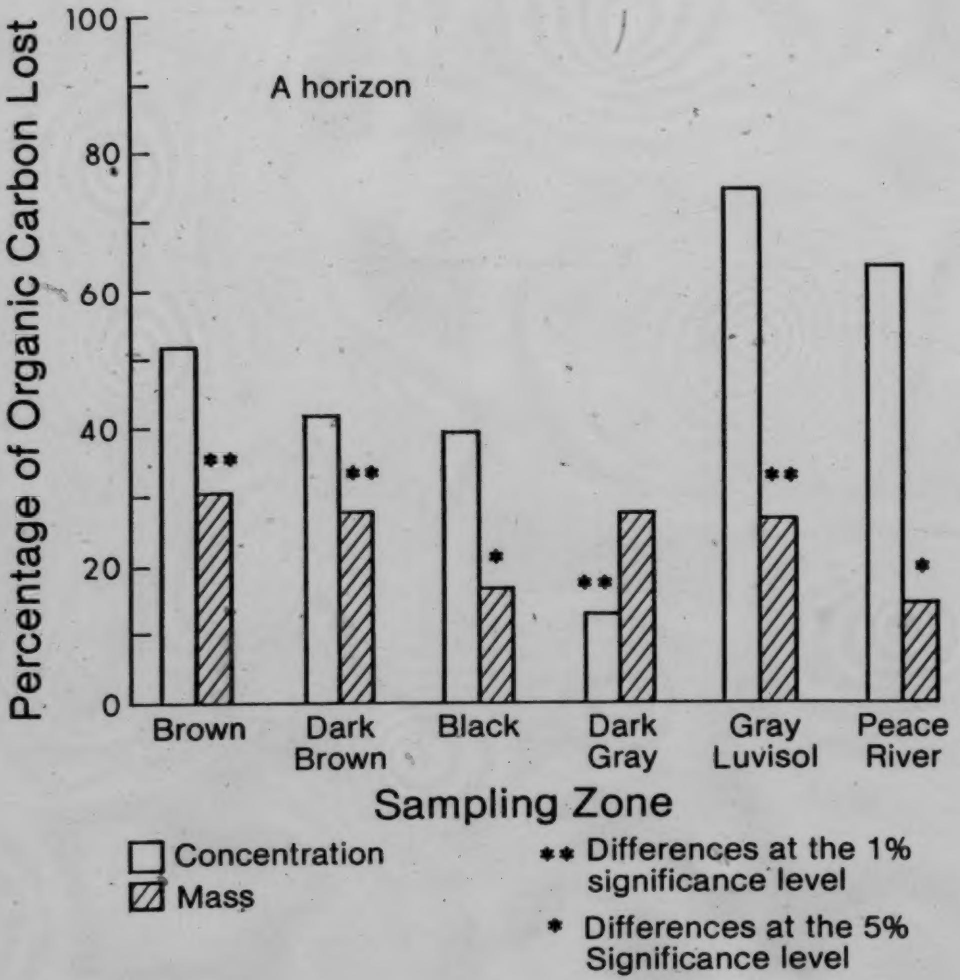

Fig.9 Average Loss in Concentration and Mass of Organic Carbon from A and/or LFH Horizons of Soils in Alberta following Cultivation.

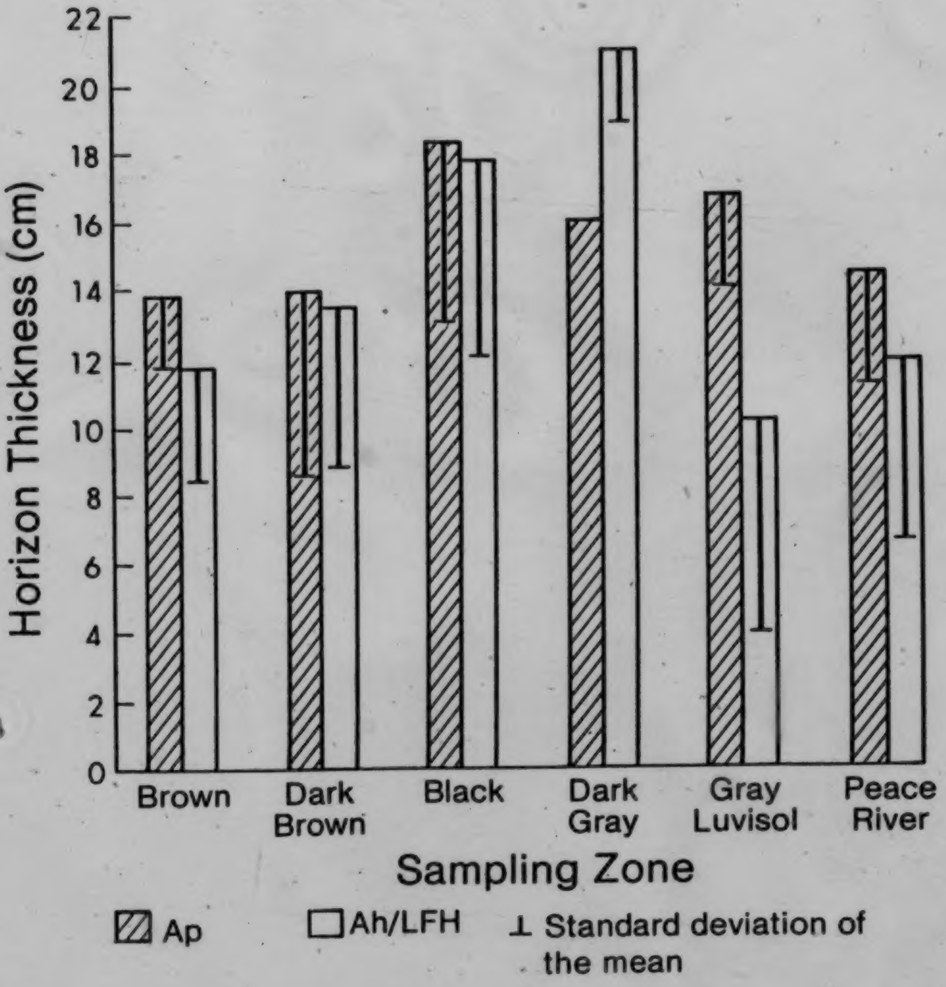

Fig. 10 Average Thickness of Cultivated and Native A and/or LFH Horizons of Soils in Alberta.

pairs was statistically significant. Similar variability in horizon depths was reported by Thiessen et al.(1982). Caldwell et al.(1939) found considerable variability in horizon depths of duplicate profiles.

4.3.6 Average Apparent Bulk Density of Cultivated and Native A Horizons

Apparent bulk density of A horizons increased through cultivation (Fig.11). Differences for the Gray Luvisolic and the Peace River soils were highly significant; differences were significant for the Brown and Black zones. There was no statistically significant difference for the Dark Brown and Dark Gray sampling zones.

4.3.7 Average pH of Cultivated and Native A Horizons

A trend toward higher pH which might have been due to horizon mixing was observed in 5 zones (Fig.12).This was only significant for the Brown and Gray Luvisolic Great Groups.

4.3.8 Distribution of Organic Carbon, Apparent Bulk Density and pH with Depth in Cultivated and Native Profiles

The distribution of apparent bulk density, pH and concentration of organic carbon with depth (Fig.s 13 to 18) shows that changes in these properties upon cultivation also occurred in subsurface horizons. Profile depths to the bottom of the B horizon were similar in cultivated and

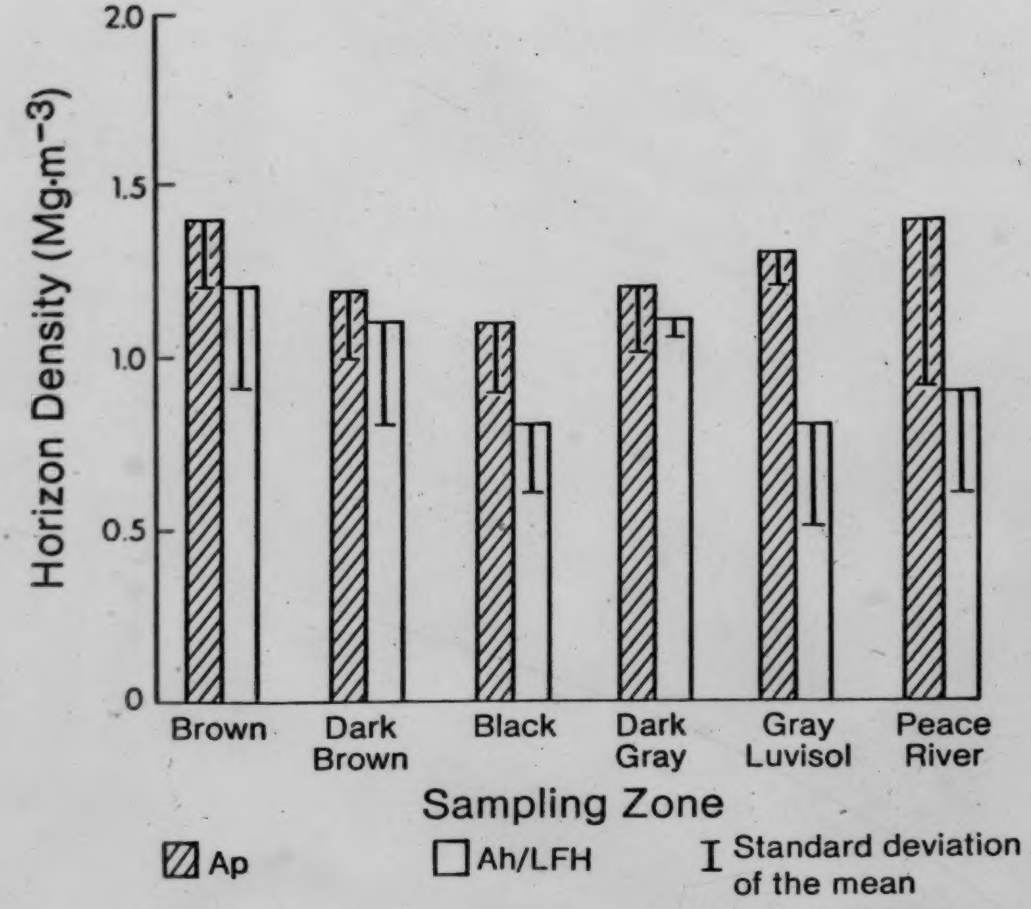

Fig. 11 Average Apparent Bulk Density of Cultivated and Native A and/or LFH Horizons of Soils in Alberta.

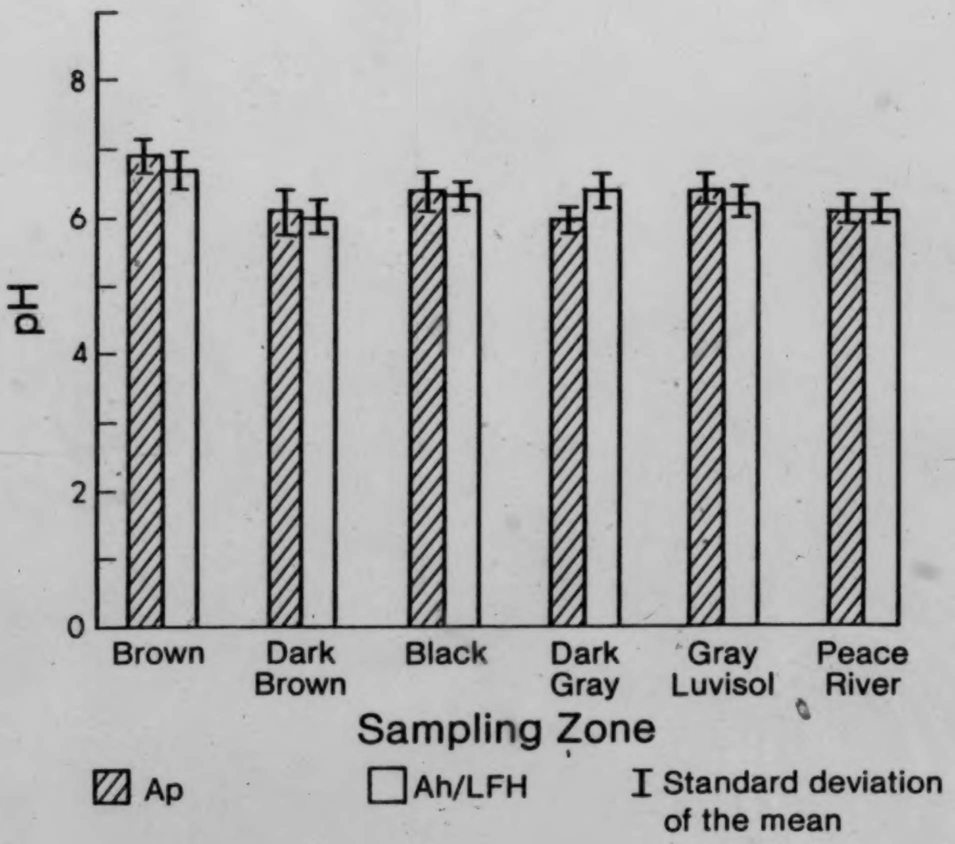

Fig.12 Average pH in Water of Cultivated and Native A and/or LFH Horizons of Soils in Alberta.

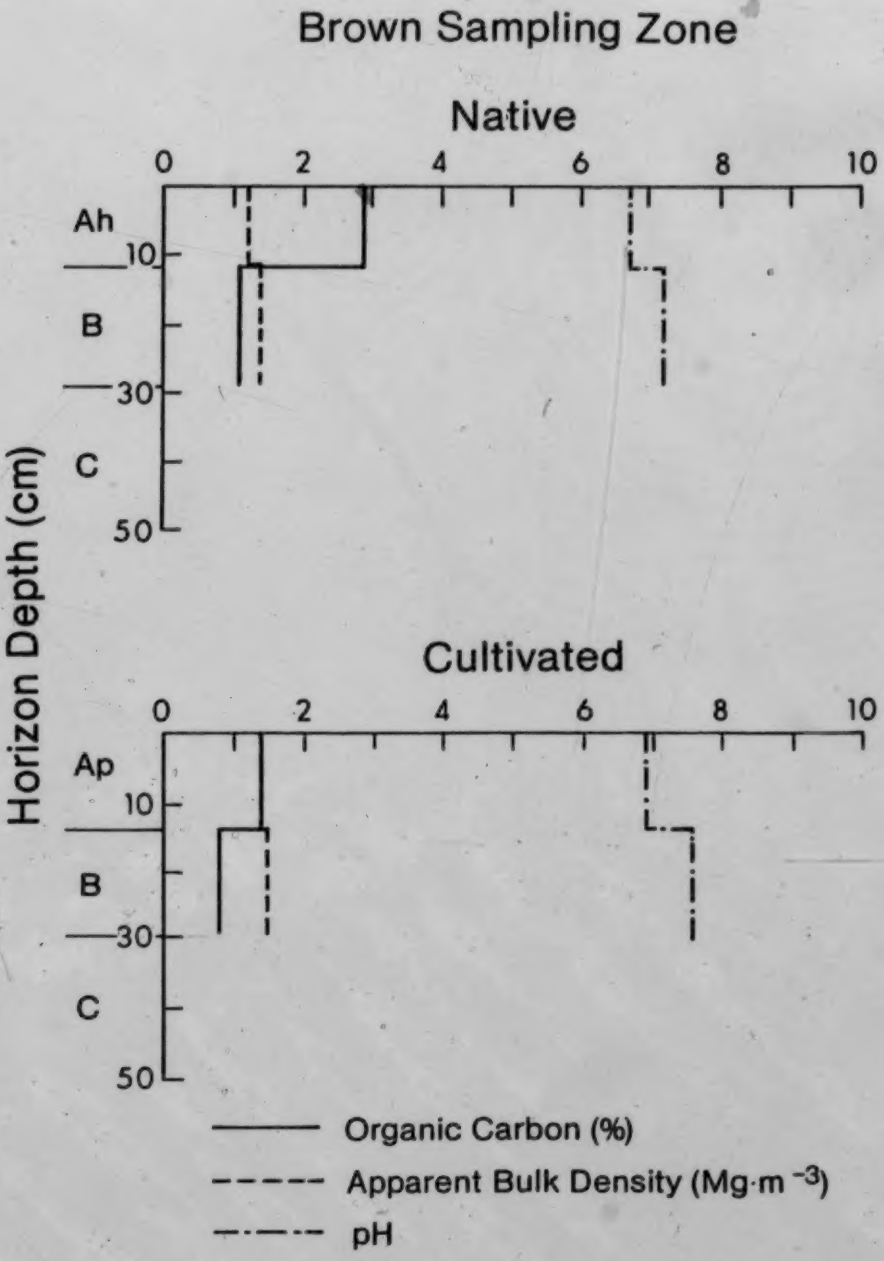

Fig.13 Distribution of Organic Carbon, Apparent Bulk Density and pH with Depth in Cultivated and Native Soils in the Brown Sampling Zone.

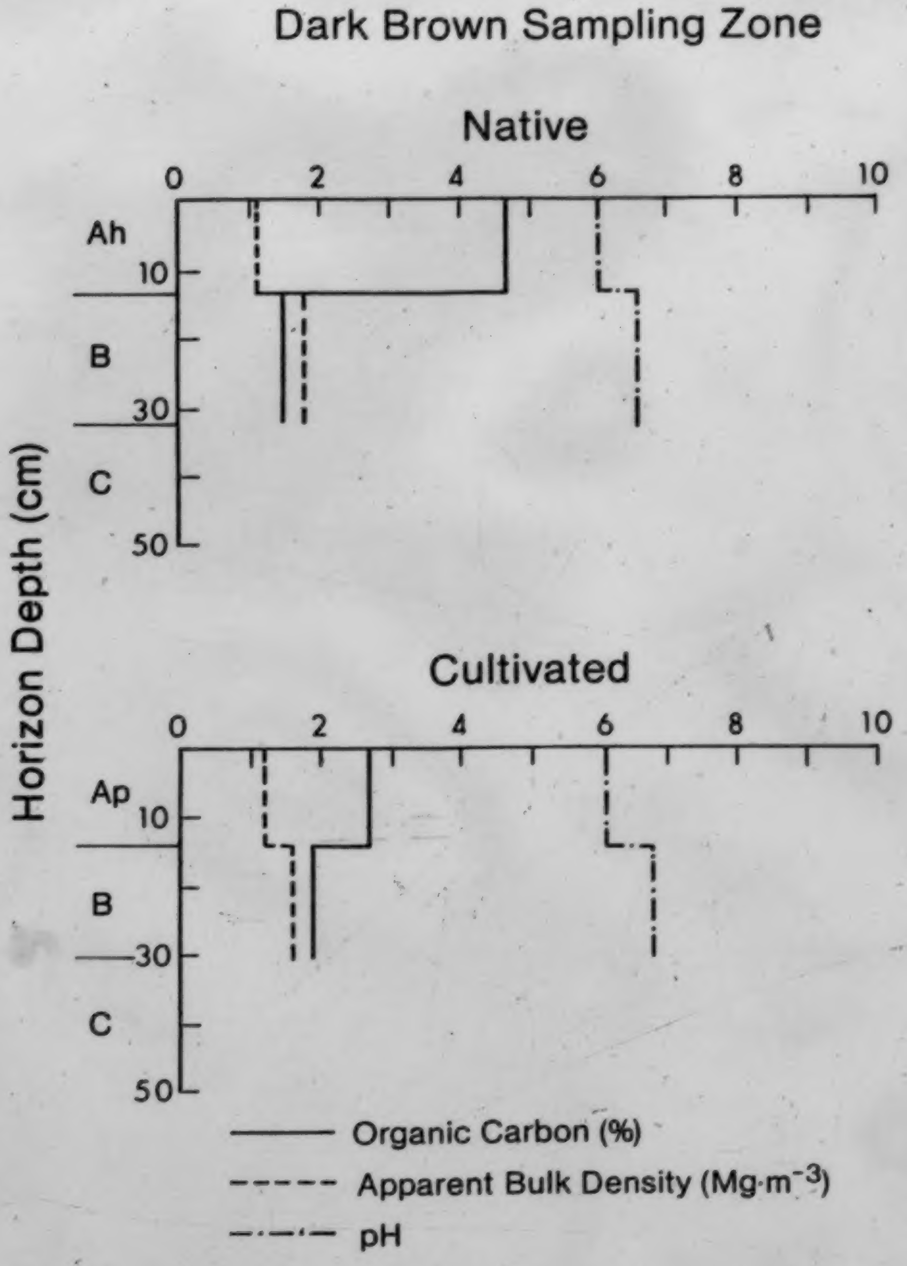

Fig. 14 Distribution of Organic Carbon, Apparent Bulk Density and pH with Depth in Cultivated and Native Soils in the Dark Brown Sampling Zone.

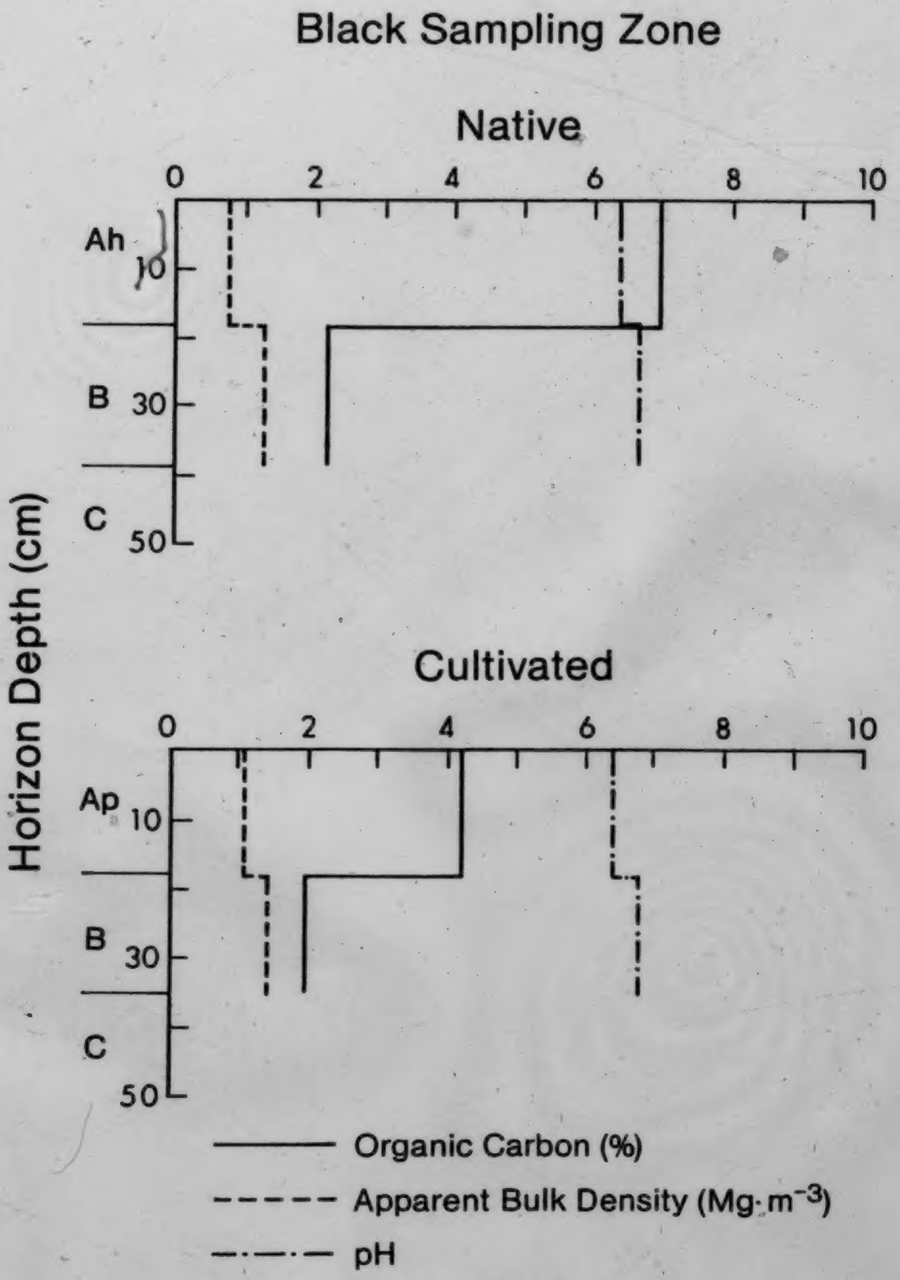

Fig.15 Distribution of Organic Carbon, Apparent Bulk Density and pH with Depth in Cultivated and Native Soils in the Black Sampling Zone.

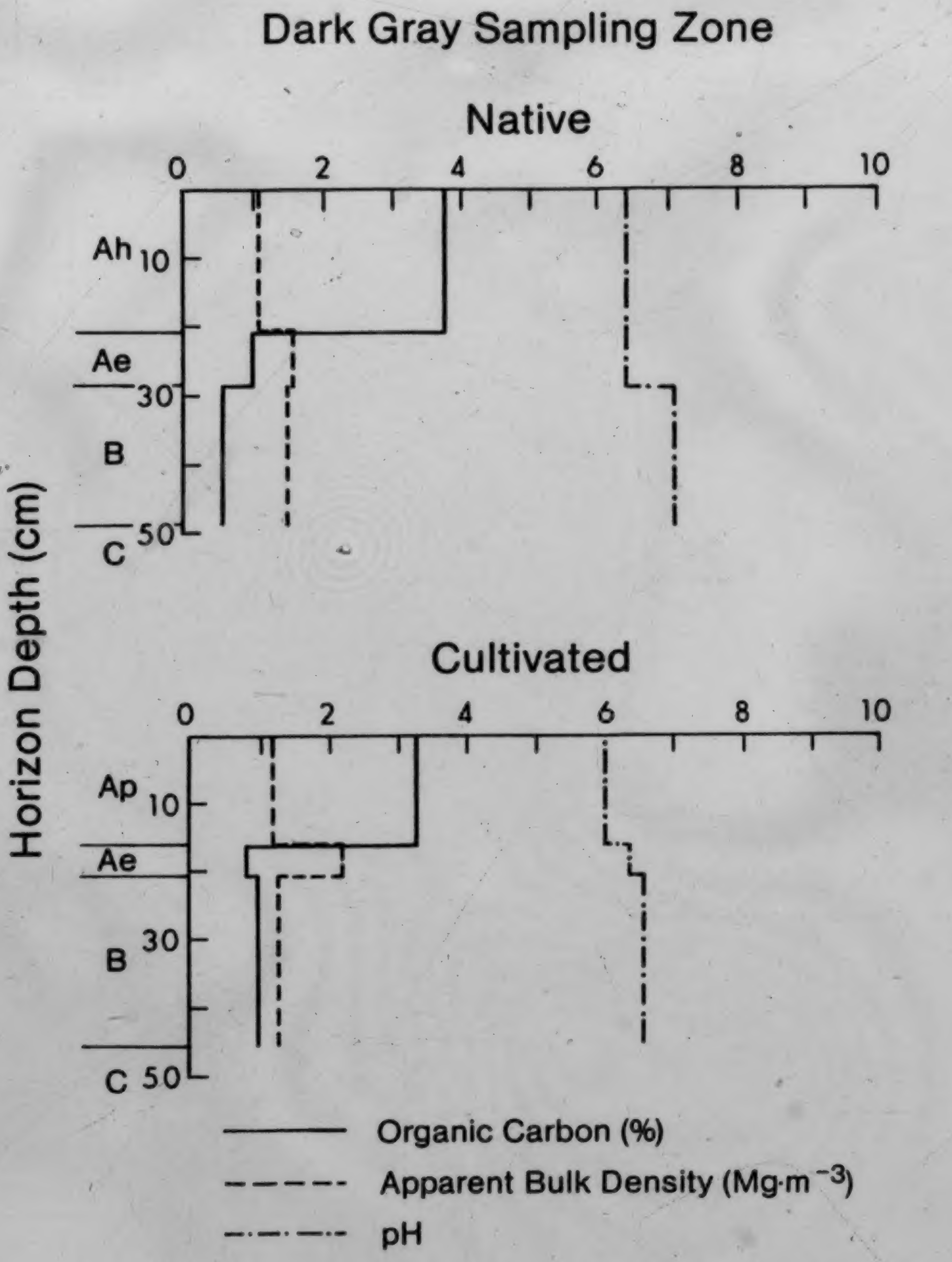

Fig.16 Distribution of Organic Carbon, Apparent Bulk Density and pH with Depth in Cultivated and Native Soils in the Dark Gray Sampling Zone.

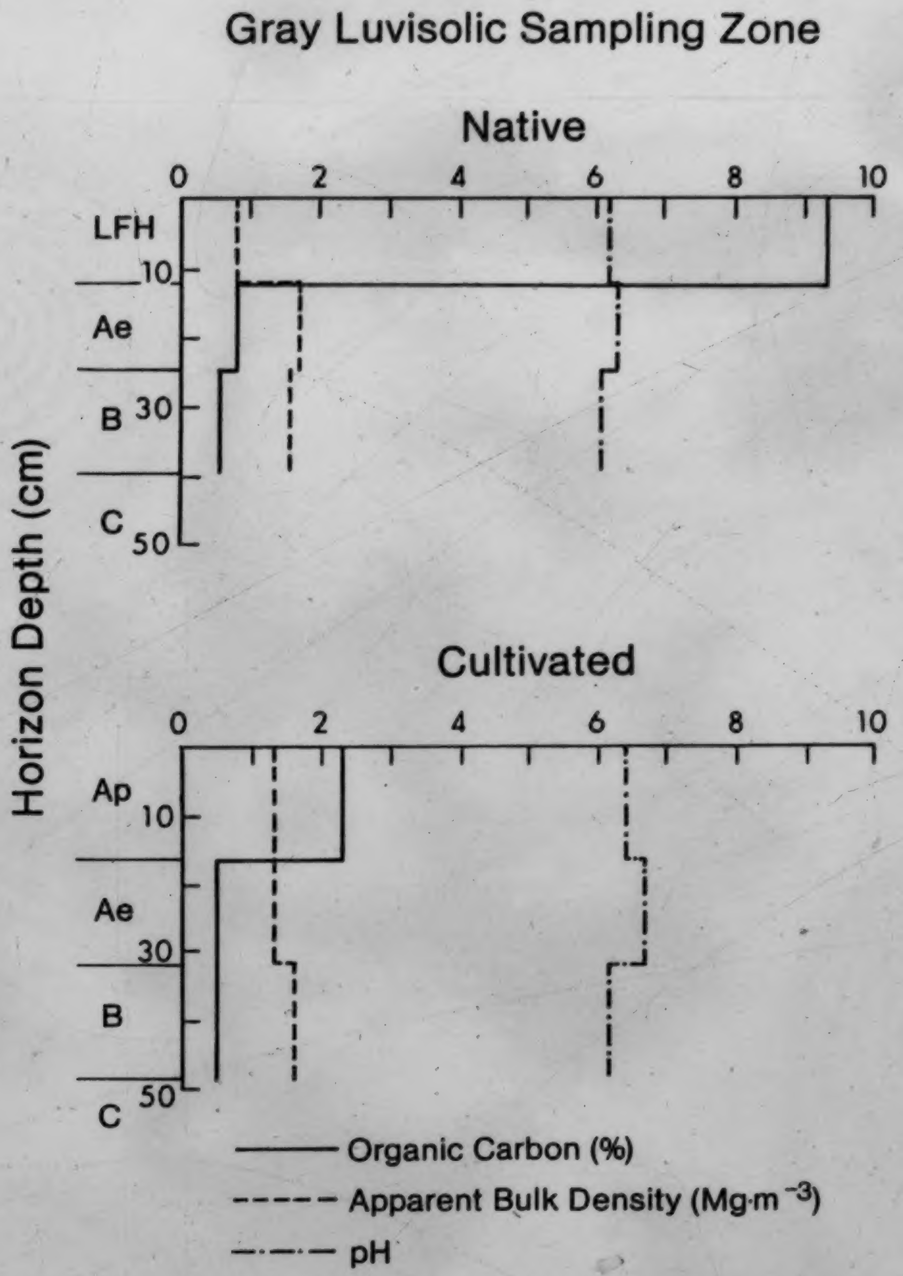

Fig.17 Distribution of Organic Carbon, Apparent Bulk Density and pH with Depth in Cultivated and Native Soils in the Gray Luvisolic Sampling Zone.

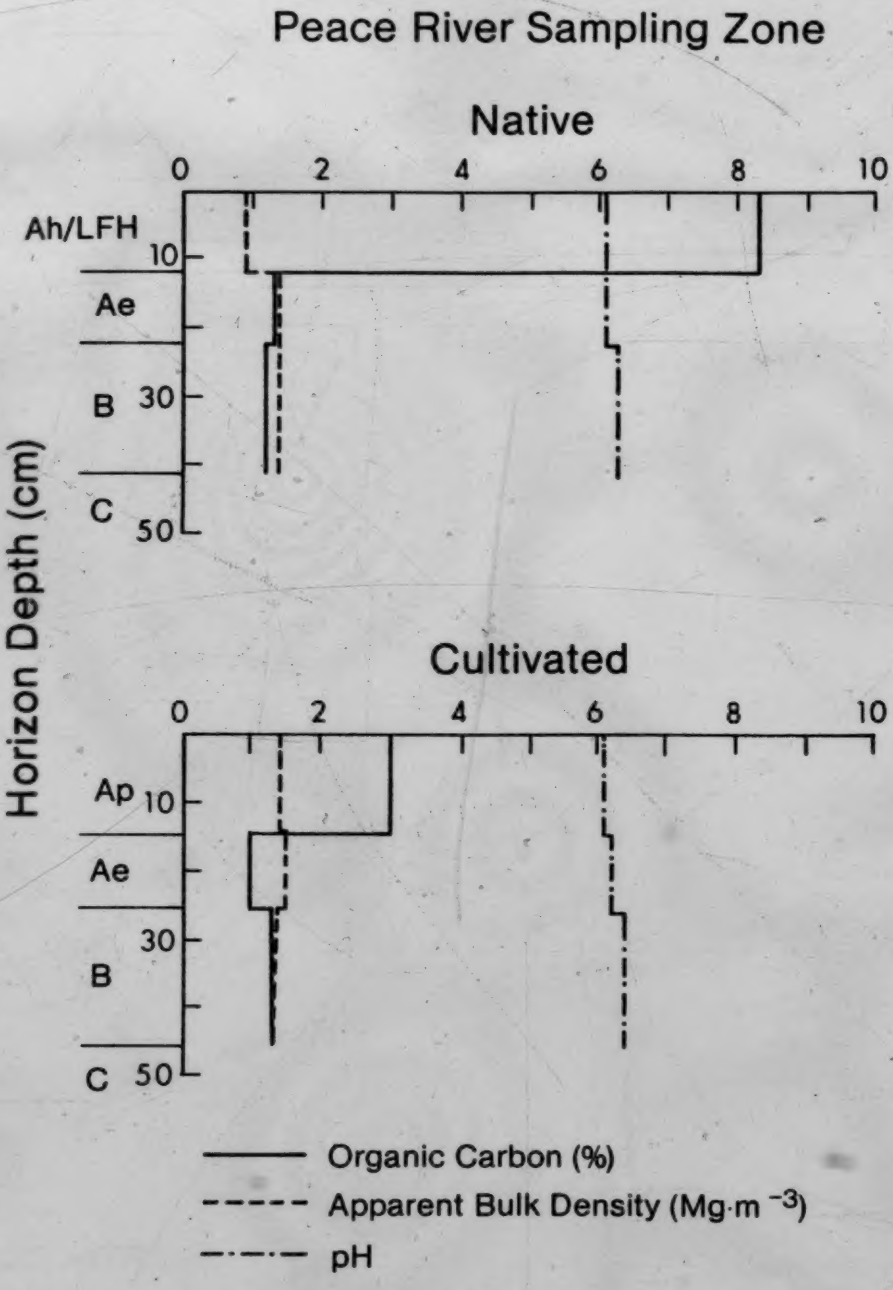

Fig.18 Distribution of Organic Carbon, Apparent Bulk Density and pH with Depth in Cultivated and Native Soils in the Peace River Sampling Zone.

native profiles except for the Gray Luvisolic soils where the cultivated profile averaged 10 cm deeper than the native profile. In all sampling zones concentration of organic carbon decreased with depth, apparent bulk density increasing simultaneously. With the exception of the Gray Luvisolic profiles, pH increased with depth. It was higher in the cultivated than in the native profiles with the exception of the Dark Gray soils. Organic carbon content in the cultivated B horizon was lower than in the native B horizon in the Brown, Black and Gray Luvisolic soils. It was higher in the cultivated than in the native B horizon for the Dark Brown, Dark Gray and Peace River soils. Changes in apparent bulk density were opposite to changes in concentration of organic carbon. Differences in concentration of organic carbon in the B horizon of the Dark Brown soils and pH in the B horizon of the Brown soils were highly significant. None of the remaining differences in properties between cultivated and native subsurface horizons were statistically significant.

4.3.9 Moisture Retention in Cultivated and Native A Horizons

Moisture retention at -33 and -1500kPa in cultivated A horizons was lower than in native A horizons in all sampling zones (Fig.19). Differences were highly significant for the Dark Brown, Black, and Peace River zones, but not statistically significant in the remaining zones.

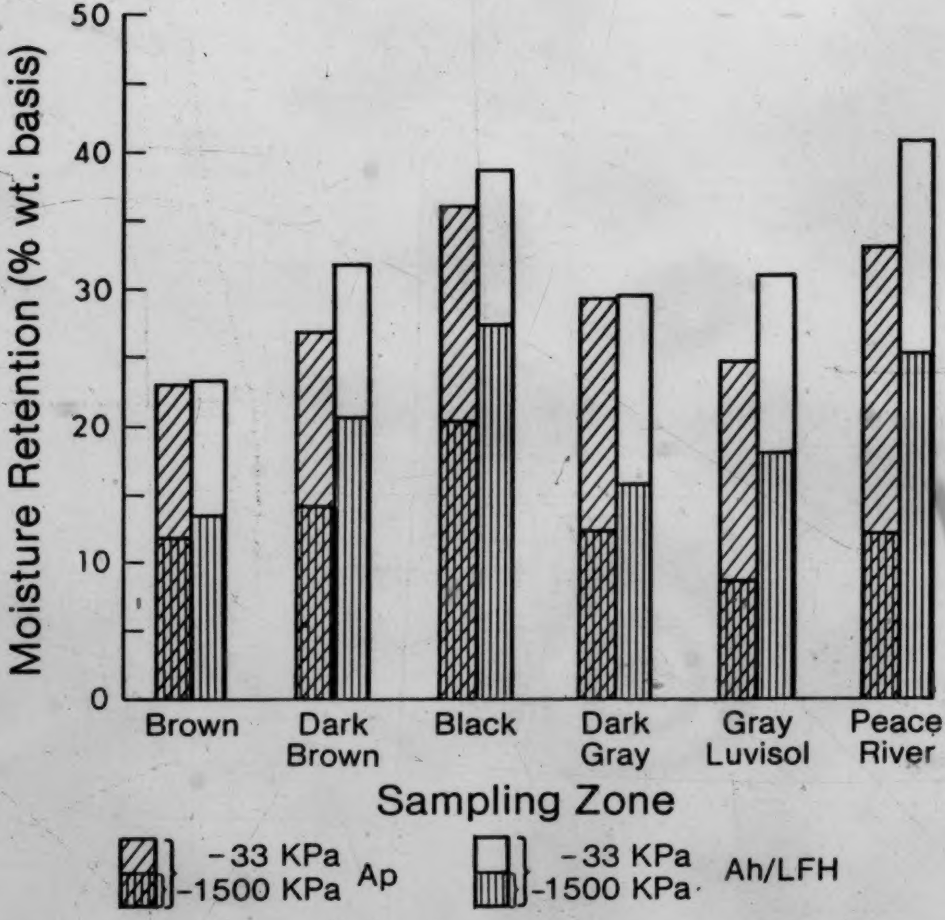

Fig.19 Average Moisture Retention at -33 and -1500 kPa in Cultivated and Native A and/or LFH Horizons of Soils in Alberta.

In all cases, moisture retention decreased more at the lower potential than at the higher potential. The result was that the difference between the two, used as an indicator for % available moisture capacity, was higher in cultivated than in native A horizons. Differences in % available moisture were highly significant for the Brown, Dark Brown and Black soils, but not statistically significant for the remaining zones.

Distribution of moisture retention at -33 and -1500kPa over the sampling zones followed the same pattern as the distribution of the mass of organic carbon in Figure 8. Moisture retention at -33 and -1500kPa was positively correlated with concentration of organic carbon and texture of the parent material; it was negatively correlated with apparent bulk density (Tables 6 and 7). Available moisture capacity in native and cultivated A horizons on the other hand increased from south to north in the sampling zones (Fig.20).

4.4 Discussion

Significant losses in organic carbon on a concentration and mass basis have occurred in the six sampling zones (Fig. 7,8,9). The data show that changes not only affected surface horizons but the complete profile (Fig. 8,13 to 18).

Similar trends were reported by Newton et al.(1945), Dormaar (1979), Dormaar and Pittman (1980), McGill et al.(1981), Voroney et al.(1981) and Campbell and Souster

Table 6 Significant ($p<0.05$)Correlation Coefficients Between Moisture Retention and Management and Soil Variables in Cultivated A Horizons

Soil Zone	Brown			Dark Brown			Black			Gray Luvisolic			Peace River		
	n=11			n=15			n=12			n=6			n=8		
VAR	AW	FC	PW	AW	FC	PW	AW	FC	PW	AW	FC	PW	AW	FC	PW
TPM	.63	.68	.68												
ORS											.94	.79			
OC					.6				.57					.88	.85
Db				-.54	-.75	-.63		-.8	-.76						
Yield										.82	.98		-.73		

VAR: variable
AW: available water(%)
FC: moisture retention at 1/3 bar
PW: moisture retention at 15 bar
OC: present concentration of organic carbon in Ap
TPM: texture of parent material
ORS: organic residue returned
Db: apparent bulk density
blank: non-significant correlations
n: number of cases in correlation

Table 7 Significant ($p<0.05$)Correlation Coefficients Between Moisture Retention and Soil Variables in Native A Horizons

Soil Zone	Brown			Dark Brown			Black			Gray Luvisolic			Peace River		
	n=12			n=16			n=12			n=5			n=11		
VAR	AW	FC	PW	AW	FC	PW	AW	FC	PW	AW	FC	PW	AW	FC	PW
TPM				.49											
OC					.60	.68									

VAR: variable
AW: available water(%)
FC: moisture retention at 1/3 bar
PW: moisture retention at 15 bar
OC: present concentration of organic carbon in Ap
TPM: texture of parent material
blank: non-significant correlations
n: number of cases in correlation

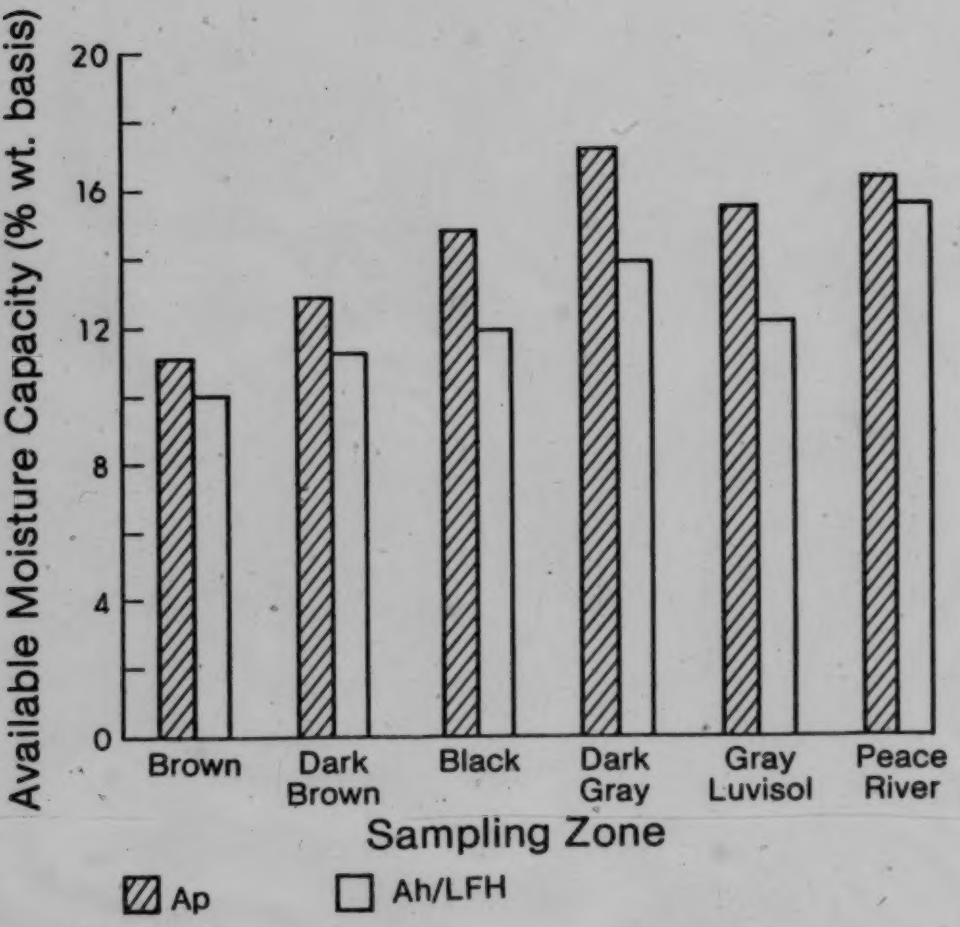

Fig.20 Average Available Moisture Capacity in Cultivated and Native A and/or LFH Horizons of Soils in Alberta.

(1982) but with different magnitude of the changes. Losses in concentration of organic carbon for the Brown soils are higher than those reported by Dormaar(1979) and Campbell and Souster(1982) (see Table 1). Losses for the Dark Brown soils are lower than comparable values for fallow rotations reported by the same authors, but somewhat higher than losses for a continuous crop rotation reported by Dormaar and Pittman(1980). Different magnitudes of the changes might be due to the different numbers of sites on which various results are based; as well as different crop rotations and years of cultivation. Results of Dormaar(1979), Dormaar and Pittman(1980) and Campbell and Souster(1982) were derived using data from one, one, and three sites, respectively, with mainly crop-summerfallow rotations. Results here are based on 14 sites in the Brown and 16 sites in the Dark Brown zone integrating fallow rotations and continuous cropping with various cultivation times.

Comparing literature results to data for farms from the present study with similar rotation and cultivation time, however, yields closer agreement. For example, two of the 14 sites in the Brown sampling zone and three of the 16 in the Dark Brown zone had losses that approximated those reported in the literature. Losses reported by Campbell and Souster(1982) for the Dark Brown soils lie within the range of losses for 11 fallow rotations of the 16 Dark Brown sites.

Mass losses in the A horizons are only about 1/3 to 2/3 of those estimated by McGill et al.(1981), and 1/3 the average loss from 3 slope positions at a Black Chernozemic site from Saskatchewan (Voroney et al.,1981; Table 2). The differences are again probably due to the present larger data base, and perhaps also to crop rotation. None of the present results for A horizons on an individual farm basis (Appendix II.3) are similar to those of Voroney et al.(1981) (Table 2).

McGill et al.(1981) predicted the lowest proportional loss for the Gray Luvisols despite their faster decomposition rate and lower initial amount of organic matter. The present results suggest that the Black soils with the slowest decomposition rate and highest initial amount had the lowest proportional loss. Estimates by McGill et al.(1981) of initial amounts are also consistently lower than present results. This creates greater proportional losses because of the smaller denominator. Their data used as the original amount of organic carbon were averages from CanSIS which included some Ap as well as Ah horizons and used literature average densities for conversion to mass. Their calculations of mass changes did not adequately treat concomitant density increase.

On the other hand, there is agreement with data of Newton et al.(1945) for the Black and Gray Luvisolic sampling zones although average cultivation time has nearly tripled and Newton's samples were taken from crop-fallow rotations. Newton et al.(1945) reported mass changes of -18% and -27% for the Black and Gray Luvisolic zones in 1945 compared to observed changes of -17% and -27% based on sampling in 1982; losses from the Brown and Dark Brown A horizons are higher than in Newton's reports. The number of sampling locations was similar in both studies; depth increments of 0-15 cm used by Newton et al.(1945) are similar to the present average horizon depths of cultivated A horizons; different methodologies for carbon determination (dry combustion vs. wet oxidation) were used, however; and bulk densities used in calculating mass were not reported by Newton et al.(1945).

Two possible patterns of mass changes in organic carbon may have occurred in the A horizons: i)losses in the Black and Gray Luvisolic zones approached a steady-state by 1945 and have not changed much since, whereas losses continued in the Brown and Dark Brown zones; or ii)organic carbon continued to decrease after Newton's investigations but, at some point in time, increased again, due perhaps to introduction of different management practices on a more extensive basis in the BL and GL zones than in the DB and BR. The overall change in organic carbon could therefore be similar now to that reported 40 years ago for the BL and GL soils. Organic matter levels for the BR and DB soils are still below those reported by Newton at al.(1945). The second scenario suggests higher organic carbon losses would have been found during some time between 1945 and 1982 than were observed in 1982.

Mass losses from the profiles of the Black soils are half of the loss (21% vs. 42%) calculated from data of Voroney et al.(1981)(Table 2), but they had only one sample site. Their reported losses are within the range of losses for crop-crop-fallow and crop-fallow rotations for 4 farms of the Black zone in the present study (Appendix II.3).

Mass losses in the subsurface horizons are up to 6 times higher than those reported by Newton et al.(1945) for the 15-30 cm depth. Despite the difference in depth increments and absence of bulk density data in reports by Newton et al.(1945), there is a suggestion that organic carbon in subsurface horizons has continued to decrease, even if changes in surface horizons might have stopped or altered direction.

The two mechanisms causing organic carbon losses are decomposition and erosion. Erosion was not measured. No reduction in profile depths seemed to have occurred (Fig.13 to 18). One has to conclude that no measurable net amount of soil was removed by erosion. Assessment of the relative magnitudes of the two processes is not possible. The variability in profile thicknesses causes such a measure of erosion to have a low resolution.

Lower losses in mass of organic carbon as opposed to concentration of organic carbon (Fig.9) may be due to two factors. First is mixing of subsurface horizon material into the A horizon during cultivation. This dilutes the concentration of organic carbon. A more negative change in concentration of organic carbon results, but with no corresponding change in mass. Changes in A horizon thicknesses (Fig.10) were greatest in soils of the Gray Luvisolic and Peace River zones which also have the highest losses on a concentration basis. Further, thickness of cultivated B horizons tended to decrease (Fig.13 to 18) which is consistent with its incorporation into Ap horizons. Second is an inverse relationship between changes in concentration of organic carbon and apparent bulk density (Fig.21). Russell(1960) and Davidson et al.(1967) reported an inverse relationship between concentration of organic carbon and bulk density., This is also evident from Fig.11 and Figures 13 to 18. Correlation coefficients between apparent bulk density and concentration of organic carbon in cultivated A horizons were -.5 for the Brown, Dark Brown and Black soils and -.6 for the Gray Luvisols in the present study. These coefficients were not statistically significant.

Deepening of A horizons, reduction in concentration of organic carbon, and increase in apparent bulk density are linked. The mass of soil in cultivated A horizons is greater than in native A horizons. The increase in soil mass exceeds the increase in depth. Therefore, a larger amount of B horizon material entered the A horizon than would be suggested by changes in horizon thickness. The associated

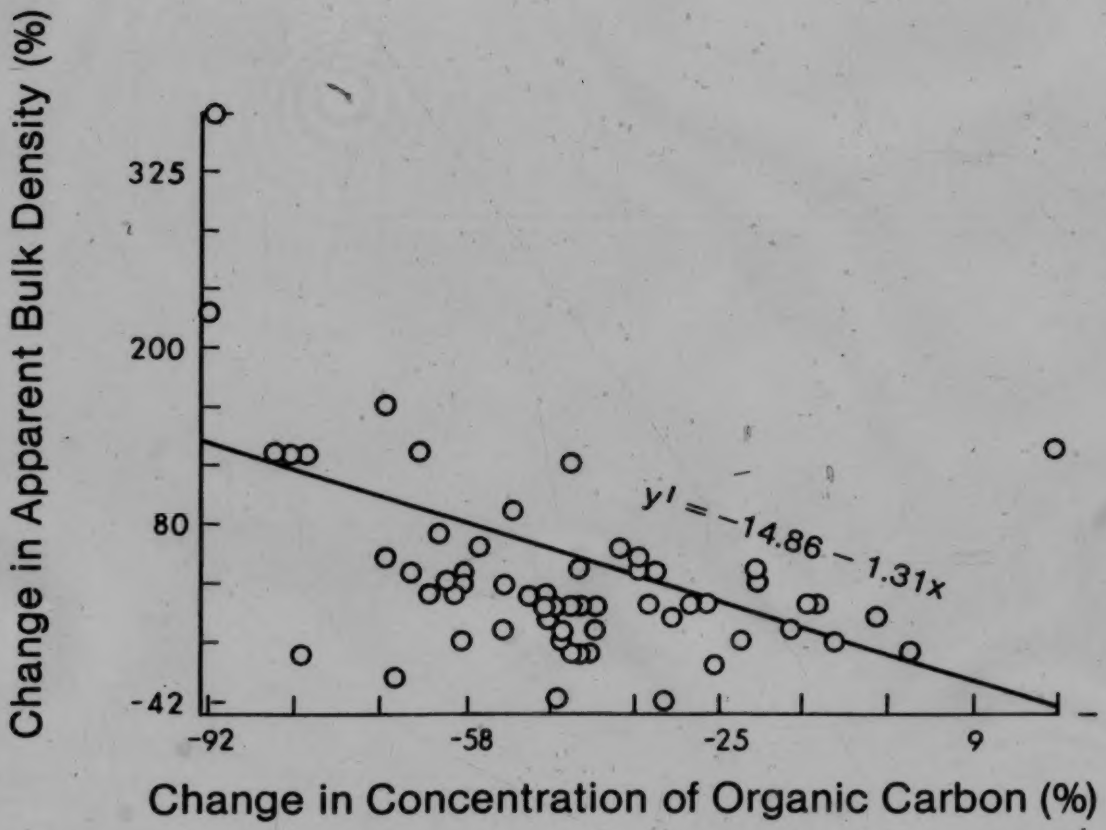

Fig.21 Relationship Between Change in Apparent Bulk Density and Change in Concentration of Organic Carbon in A Horizons of Soils in Alberta (r=0.47; p<0.0001; [illegible]=64).

increase in bulk density has prevented the extent of dilution from being obvious.

Concern about changes in concentration or changes in mass of organic carbon will depend on whether qualitative (e.g. aggregation) or quantitative (e.g. nutrient supply) aspects of organic matter are of interest. With regard to maintenance of productivity both are equally important.

Available moisture capacity in cultivated A horizons was higher than in native A horizons in all sampling zones because moisture retention decreased more at -1500kPa than at -33kPa. Moisture retention at -33kPa and -1500kPa increased with increasing mass of organic carbon. This suggests that organic matter influences moisture retention both at low and high potentials, but apparently more at the lower than at the higher potential. Such a conclusion was also reached by De Jong et al.(1983).

Clay and bulk density are also positively correlated with moisture retention (Hutcheon,1942; Hill and Sumner, 1967; Shaykewich and Zwarich,1968; Reeve et al.,1973; De Jong et al.,1983). Shaykewich(1980) concluded that particle size distribution was more important in its influence on available moisture capacity than organic matter. The tendendy for clay contents to increase from south to north throughout the province may be related to the increase in available moisture capacity (Fig.20). No particle size determination was conducted for the individual samples;

texture of the parent material was estimated by hand.

Actual moisture available under field conditions, is additionally influenced by pore size distribution and infiltration rate. Both of these properties depend on texture-organic matter-bulk density relationships. The linking factor is aggregation. Organic matter improves aggregation and root penetration; it thus allows a larger volume of soil to be explored by roots and potentially more moisture to be taken up by plants (Allison,1973).

Determination of available moisture capacity on disturbed samples will therefore not completely describe the effect of changes in organic carbon on moisture regimes in the field.

4.5 Conclusions

Significant losses in concentration and mass of organic carbon in A horizons and profiles occurred through cultivation. Losses in concentration of organic carbon were significantly higher than losses in mass of organic carbon in most cases. This has been attributed to the combined effects of: i) dilution due to mixing of subsurface horizon material into the original A horizon; and ii) an inverse relationship between changes in apparent bulk density and changes in concentration of organic carbon. Both of these mechanisms are linked.

Depending on the sampling zone, variable gains in mass of organic carbon occurred on 13% to 43% of the farms for A horizons and on 13% to 33% of the farms for the profile.

Thickness of A horizons increased due to cultivation except in the Dark Gray soils. None of the differences in horizon pairs was statistically significant which was attributed to great variability in horizon thickness.

Apparent bulk density in A horizons increased due to cultivation in all sampling zones. The increase was not statistically significant in the Dark Brown and Dark Gray sampling zones.

No reduction in profile depths occurred due to cultivation. Losses of organic carbon therefore were attributed mainly to decomposition. No measurement of erosion was conducted to confirm this conclusion.

Organic carbon changes influenced moisture retention more at lower than at higher potentials. Consequently available moisture capacity increased in cultivated A horizons.

The magnitude of the change in organic carbon depends on the method of calculation. The method used in this study corresponds to that used in the literature and normally yields the most negative changes.

Losses reported in the literature correspond to two of the 14 sites in the Brown sampling zone and three of the 16 sites in the Dark Brown sampling zone, if crop rotations and cultivation time were similar. Although the literature values correspond to some individual farms, they do not appropriately represent the average for any soil zone. A larger number of sites is needed than has been used in the past. Comparison with data from Newton et al.(1945) suggests that losses may have ceased in the Black and Gray Luvisolic sampling zones.

5. Regional and Management Variables Affecting Changes in Soil Organic Carbon

5.1 Introduction

The objective of this section is to examine the effects of regional and management variables on changes in organic carbon presented in the previous chapter. Management data used cover the period from 1982 to 1967. Many missing data between 1967 and 1907 made regression analyses for that period impossible.[2]

5.2 Methods of Statistical Analysis

The overall dependence of a criterion variable such as present concentration of organic carbon on a single or set of independent (predictor) variables (management data, soil properties) was assessed by simple linear and stepwise forward multiple linear regression techniques. Statistical analysis was performed using SPSSx subprograms Scattergram and Regression. Only farms with complete data sets were analyzed statistically. The Dark Gray sampling zone, represented by only two farms, was eliminated.

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[2] Data codes are listed in Appendix I. Ascending numerical values for crop rotation represent lower fallow frequency and more continuous cropping as numbers increase; ascending numbers for organic residue represent quantitatively (e.g. straw chopped) and qualitatively (e.g.manure) higher return. Tillage intensity and input of N and P increase with ascending numbers.

5.3 Results

5.3.1 Characteristics of Management Practices throughout Alberta

The proportion of various management practices in the sampling zones is summarized in Table 8. Percentages are of the total number of farms for which data were available.

Fields in the Brown sampling zone had the lowest average cultivation time of 38 years. No data were available for three farms and four out of the remaining 11 fields had been cultivated for only three, six, ten and 18 years, respectively. Fields in the Black and Dark Brown zone had similar cultivation time of around 60 years; data for one farm were missing in the Black zone. The Peace River area was under cultivation longer than the Gray Luvisolic zone; data from three farms were missing in the Peace River area.

On a provincial level, summerfallowing in combination with stubble mulching was the most common practice, being applied to 51% of the fields sampled. Some of these fields were cultivated with a noble blade to reduce tillage intensity. Continuous cropping on the other hand had a frequency of 44%. Mineral N and P were applied to 86% of the fields during some time in the 15 years previous to sampling; 20% of the total fields received fertilizer only during five years prior to sampling.

Within the sampling zones, fields of the Brown zone had the highest proportion of summerfallowing and stubble

TABLE 8: RELATIVE FREQUENCIES OF MANAGEMENT PRACTICES ON FARMS SAMPLED IN ALBERTA (1982-1967)

MANAGEMENT PRACTICE	BROWN %	DARK BROWN %	BLACK %	GRAY LUVISOL %	PEACE RIVER %	TOTAL %
SUMMERFALLOW	73	69	29	42	44	51
CONTINUOUS CROPPING	27	31	64	29	56	44
LAY FARMING			7	29		5
STRAW REMOVED		20	7	29	11	11
STUBBLE MULCH	82	73	43	29	67	60
MANURE		7	14	14	11	9
GREEN MANURE				14	11	3
ALL STRAW RETURNED	18		36	14		17
ADDITION	18[1]	67	93	57	89	66
OF N	46[2]	13	7	29	11	20
NO N	36	20		14		14
ADDITION	18[1]	67	93	57	89	66
OF P	36[2]	13	7	29	11	18
NO P	46	20		14		16
CONVENTIONAL TILL	45	40	71	57	50	53
EXCESSIVE TILL	55	60	29	43	50	47
NUMBER OF FARMS*	11	16	14	7	9	57
AVERAGE CULTIVATION TIME*	38	61	60	40	50	

[1]: Proportion of farms adding fertilizer annually between 1982 and 1967
[2]: Proportion of farms adding fertilizer annually only during the period between 1982 and 1977
*Absolute numbers

mulching followed by the Dark Brown zone; in both zones use of the noble blade was not uncommon. More continuous cropping was practiced on fields in the Dark Brown zone than in the Brown zone.

Whereas nearly 70% of the fields sampled in the Dark Brown zone had regular inputs of mineral N and P since 1967, only 18% in the Brown zone did so. In the Brown zone 46% of the fields had not received mineral fertilizer until five years prior to sampling time. The highest relative frequency of continuous cropping, manuring, amount of straw returned, N and P applications and conventional tillage was on fields of the Black sampling zone. Continuous cropping and application of mineral fertilizer had second highest frequency in the Peace River area after the Black sampling zone. Continuous cropping and lay farming were not uncommon in the Gray Luvisolic zone and mineral N and P were used more frequently than in the Brown zone. Green manuring had frequencies of 14% and 11% in the Gray Luvisolic and Peace River zones, respectively.

Fertilizer N input started some time between 1947 and 1967 (Table 9). Annual inputs to fallow rotations were very low. Mineral P was not applied until some time after 1967 (Table 10). Simultaneously, continuous cropping became more frequent after 1967 entailing a considerable increase in mineral N and P input (Table 9 and 10). The highest average annual input of N between 1982 and 1977 was in the Black and Peace River zones under continuous cropping. The highest

TABLE 9 AVERAGE ANNUAL N INPUTS (kg·ha⁻¹) TO CEREAL CROPS UNDER VARIOUS ROTATIONS BETWEEN 1982 AND 1907.

ZONE	1982 - 1977			1977 - 1967			1967 -1947			1947 -1927			1927 - 1907	
	CR-SF N	CR-CR-SF N	CC N	CR-SF N	CR-CR-SF N	CC N	CR-SF N	CR-CR-SF N	CC N	CR-SF N	CR-CR-SF N	CC N	CR-SF N	CR-CR-SF N
BR	3		55			67*								
DB	17	12	50	2	7	35	1							
BL	6	27	61	3	27	40	2	3						
GL		23	43		3									
PR		13	66		22	24		3						

TABLE 10 AVERAGE ANNUAL P INPUTS (kg·ha⁻¹) TO CEREAL CROPS UNDER VARIOUS ROTATIONS BETWEEN 1982 AND 1907.

ZONE	1982 - 1977			1977 - 1967			1967 -1947			1947 -1927			1927 - 1907	
	CR-SF P	CR-CR-SF P	CC P	CR-SF P	CR-CR-SF P	CC P	CR-SF P	CR-CR-SF P	CC P	CR-SF P	CR-CR-SF P	CC P	CR-SF P	CR-CR-SF P
BR	1		18			25*								
DB	6	4	16	4	4	14								
BL	7	7	14	5	7	15								
GL		36	18		2									
PR		4	16		10	11								

BR: Brown; DB: Dark Brown; BL: Black; GL: Gray Luvisolic; PR: Peace River
CR-SF: crop-summerfallow; CR-CR-SF: crop-crop-summerfallow
CC: continuous cropping; * only one farm

average annual P input during the same period was to crop-crop-summerfallow rotations in the Gray Luvisolic zone. In the remaining areas, however, N and P input were many times higher under continuous cropping than under fallow rotations.

Cereal yields seem to have increased concomitantly with fertilizer input (Table 11). This is consistent with yield trends for the three prairie provinces reported by Ridley and Hedlin (1980). Highest average annual grain yields were achieved under continuous cropping; under this management the Black sampling zone had the highest average yield amongst the sampling zones.

5.3.2 Relationship between Crop Rotation and Change in Organic Carbon

Losses in concentration and mass of organic carbon were consistently lower under continuous cropping than under fallow rotations in the Brown, Dark Brown and Black zones (Table 12). Higher losses under continuous cropping in the Gray Luvisolic and Peace River sampling zones were probably due to the presence of LFH horizons amongst the native horizons.

5.3.3 Simple Linear Regression Models

Simple linear regressions were performed for each of the dependent variables:

1. concentration of organic carbon in cultivated A horizons;

TABLE 11 AVERAGE ANNUAL YIELDS (Y) ($Mg \cdot ha^{-1}$)OF CEREAL CROPS UNDER VARIOUS ROTATIONS BETWEEN 1982 AND 1907.

ZONE	1982 - 1977			1977 - 1967			1967 -1947			1947 -1927			1927 - 1907	
	CR-SF Y	CR-CR-SF Y	CC Y	CR-SF Y	CR-CR-SF Y	CC Y	CR-SF Y	CR-CR-SF Y	CC Y	CR-SF Y	CR-CR-SF Y	CC Y	CR-SF Y	CR-CR-SF Y
BR	1.1		3.0	0.8		4.8*	0.8			0.8				
DB	1.2	1.5	2.6	1.1	1.5	2.1	0.9	1.1		0.8	1.2		0.9	0.9
BL	1.4	1.7	3.9	1.4	1.7	3.8	1.0	1.5		1.1	1.5		1.0	1.5
GL		1.9	**		1.7			1.4						
PR		1.3	2.8		1.7	2.7		1.6			0.8			1.2

BR: Brown; DB: Dark Brown; BL: Black; GL: Gray Luvisolic; PR: Peace River
CR-SF: crop-summerfallow
CR-CR-SF: crop-crop-summerfallow
CC: continuous cropping
* only 1 farm
** missing

TABLE 12 AVERAGE CHANGE IN CONCENTRATION AND MASS OF ORGANIC CARBON(OC) IN A HORIZONS UNDER SUMMERFALLOW (SF)AND UNDER CONTINUOUS CROPPING (CC)

SAMPLING	LOSS IN CONCENTRATION (%)					LOSS IN MASS (%)		
ZONE	SF	n	CC	n	Av.Z.[1]	SF	CC	Av.Z.[1]
BROWN	-58	8	-35	3	-52	-29	-25	-31
DARK BROWN	-48	11	-40	5	-42	-33	-16	-28
BLACK	-52	4	-45	9	-40	-25	-22	-17
GRAY LUVISOLIC	-66	3	-84[2]	2	-75	00	-38	-27
PEACE RIVER	-51	4	-62[2]	5	-64	-23	+29[3]	-15

n: number of farms
Av.Z.: average for sampling zone
[1] contains all farms per sampling zone
[2] biased with one LFH horizon; low number of cases
[3] biased with one high gain; low number of cases

2. change in concentration of organic carbon in the A horizon;
3. change in mass of organic carbon in the A horizon;
with the predictor variable years of cultivation.

The purpose was to examine whether there was a defined relationship between any of the independent variables and the criterion variable; and to determine the direction of this relationship. The overall pattern of the scatter was used as an indicator for any systematic relationship among the data represented.

Relationship between Change in Organic Carbon and Time

On a provincial level, a weak but positive correlation existed between present concentration of organic carbon and time (Appendix III.1).

On a sampling zone level the only statistically significant trend was in the Brown sampling zone, where 31% ($p<0.05$) of the variability in change in concentration of organic carbon was explained by years of cultivation, the direction being negative (Appendix III.2). Data points showed a curvilinear trend (Fig.22).

The change in organic carbon with time has been described as a negative curvilinear relationship (Henin and Dupuis,1945; Woodruff,1949). Initially, organic carbon decreases rapidly with the slope levelling off afterwards. Apart from the Brown zone (Fig.22) none of the scattergram patterns indicated such a relationship. The Black sampling

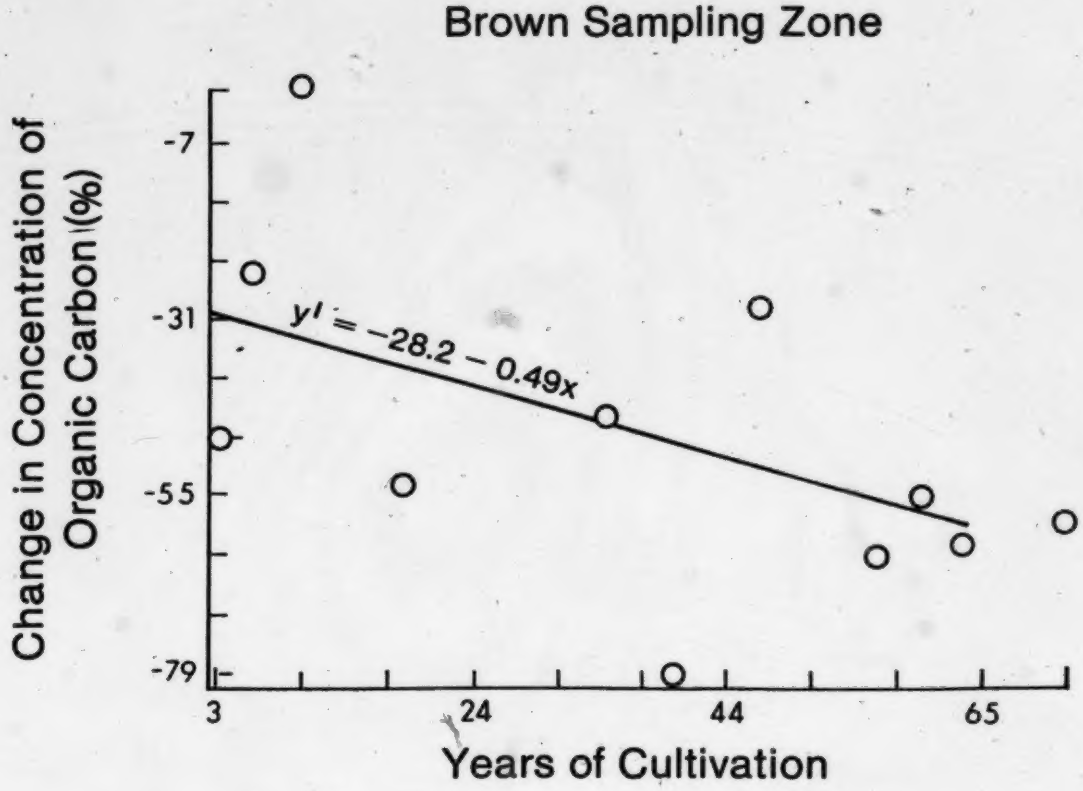

Fig.22 Relationship Between Change in Concentration of Organic Carbon and Time in the Brown Sampling Zone (r=-0.56; p=0.04; n=11).

zone (Fig.23) was chosen to represent trends in the remaining sampling zones. There did not seem to be any systematic relationship with time among the data represented.

In the Gray Luvisolic zone a positive correlation of +.58 existed between change in mass of organic carbon and years of cultivation at a significance level of 8% (Appendix III.3).

Influence of Management Practices on Change in Organic Carbon With Time

A second set of simple linear regressions was performed for the dependent variables described and cultivation time as a predictor variable when different kinds of crop rotations were practiced and different kinds of organic residues returned. Crop rotations and organic residues were as described in Table 8 and as coded in Appendix I (File Cropinfo). The objective was to determine if prediction accuracy of change in organic carbon with time could be improved.

On a province level, 13% of the variability (n=26)in present concentration and change in concentration of organic carbon was explained by years of cultivation if continuous cropping was practiced. The slope was positive (Appendix III.4). When straw was removed which was the case for 6 farms, 80% of the variability in present concentration and change in concentration of organic carbon was explained by

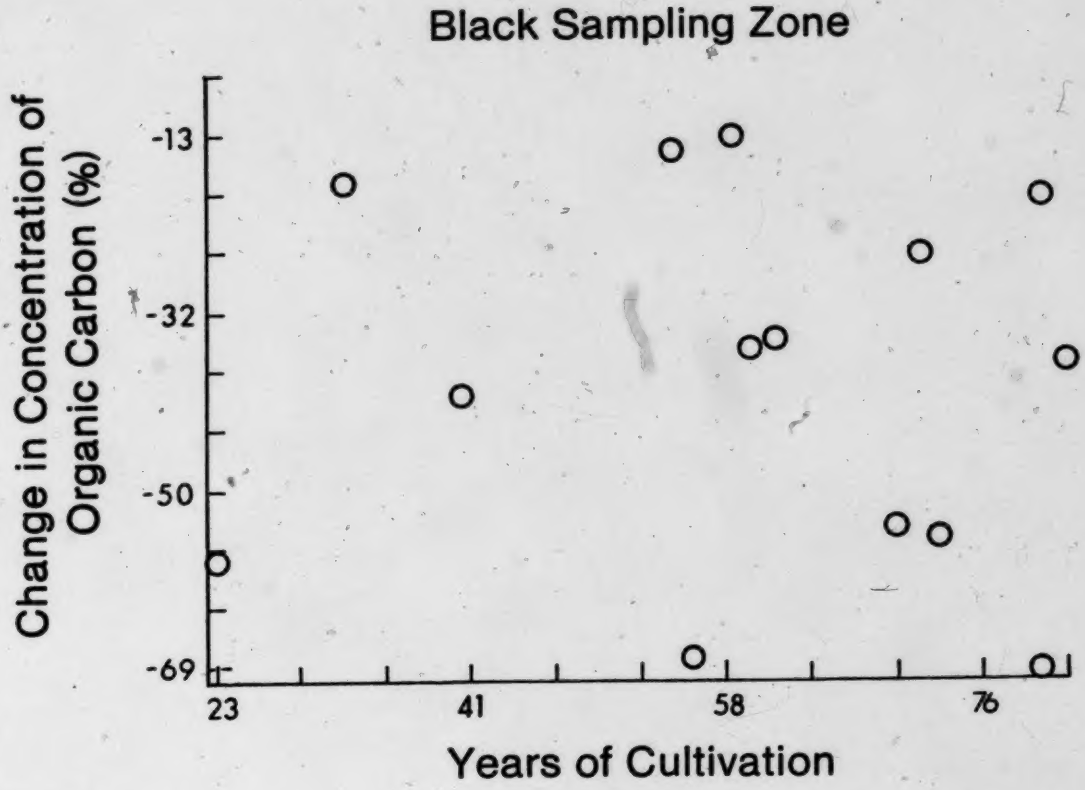

Fig.23 Relationship Between Change in Concentration of Organic Carbon and Time in the Black Sampling Zone (r=-0.05; p=0.43; n=14).

years of cultivation. Continuous cropping was simultaneously practiced on 50% of these farms, however.

On a sampling zone level, four statistically significant trends were obvious:

1. Brown zone: In stubble mulch systems 41% of the variability in the change in mass of organic carbon was explained by cultivation time (Appendix III.5). Stubble mulching in combination with summerfallowing was common. Although not statistically significant, a negative relationship existed between change in concentration of organic carbon and cultivation time if summerfallowing was practiced (Fig.24).

2. Dark Brown zone: If straw was removed (three farms), 99% of the variability (positive slope) in mass change of organic carbon was explained by cultivation time (Appendix III.6). Two of the three farms, however, had practiced continuous cropping for 15 years. The third farm site had been under a crop-crop-fallow rotation for 60 years (1917-1977), but the field was put under pasture in the 5 years previous to sampling which seems to have had an effect on rebuilding organic matter. The high correlation obtained has to be interpreted with great care, however, because only three data points were present. This reduces the degrees of freedom to a minimum and can result in apparently high correlation of unrelated populations.

3. Gray Luvisolic zone: In crop-crop-fallow rotations 97% of the variability in present concentration of organic carbon

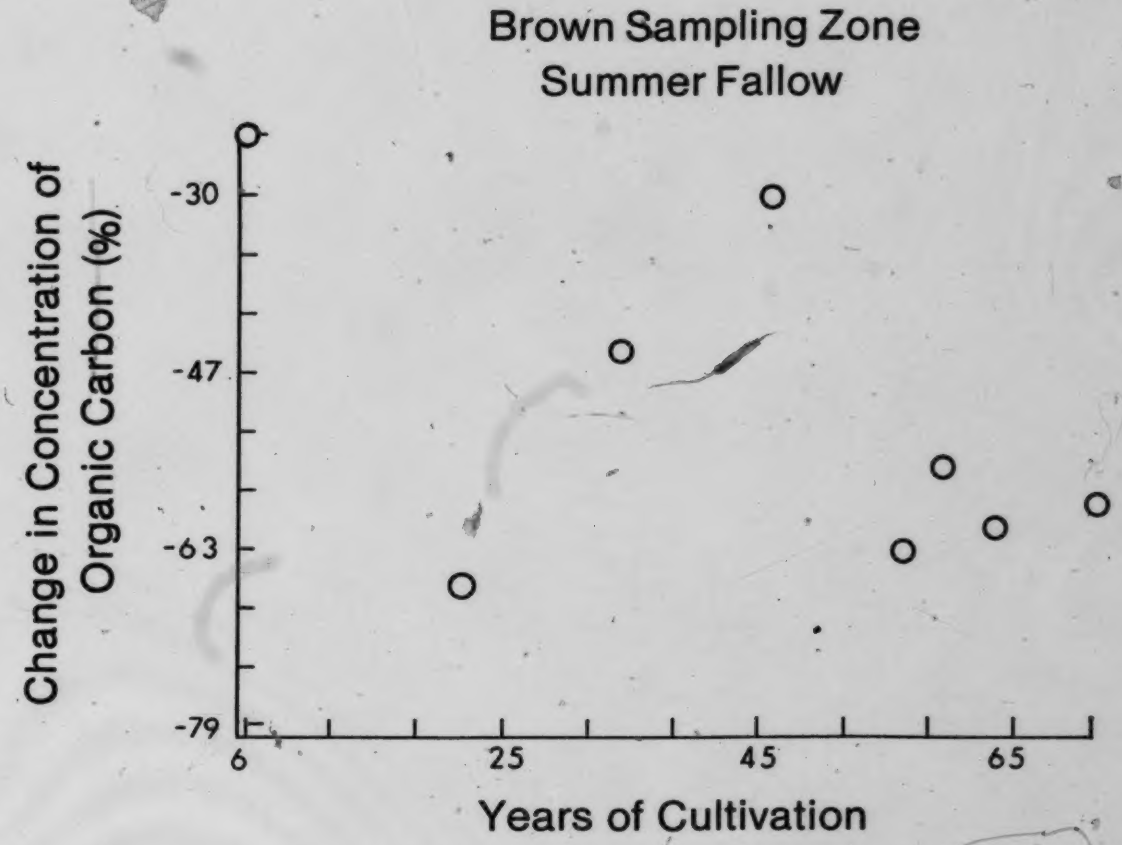

Fig.24 The Influence of Summerfallowing on the Relationship Between Change in Concentration of Organic Carbon and Time in the Brown Sampling Zone (r=-0.56; p=0.07; n=8).

was explained by cultivation time. The slope was slightly negative (Appendix III.8). This was the case for only three farms and the high correlation is of little meaning.

4. Peace River zone: When summerfallowing was practiced 95% of the variability in change in concentration of organic carbon was explained by cultivation time. The slope was positive (Appendix III.9). Again, only four cases were present causing problems as mentioned for the Dark Brown and Gray Luvisolic zone.

No statistical significance existed between the change in concentration of organic carbon and time in the Black zone when continuous cropping was practiced (Fig.25).

Significance and correlation between change in concentration of organic carbon and cultivation time were not improved by taking management practices into account (statistics at bottom of Fig.24 and 25). The direction of the relationship, however, remained consistent. Yet, much of the variability in organic carbon change remained unexplained.

Logarithmic Transformation

The relationship between organic carbon and time is frequently expressed by plotting log % of the original carbon content[3] versus time in order to account for first order loss. Log transformation did not increase the probability of a higher correlation (Fig.26,27,28 and 29).

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[3] % of original OC = (present % OC/original % OC)100

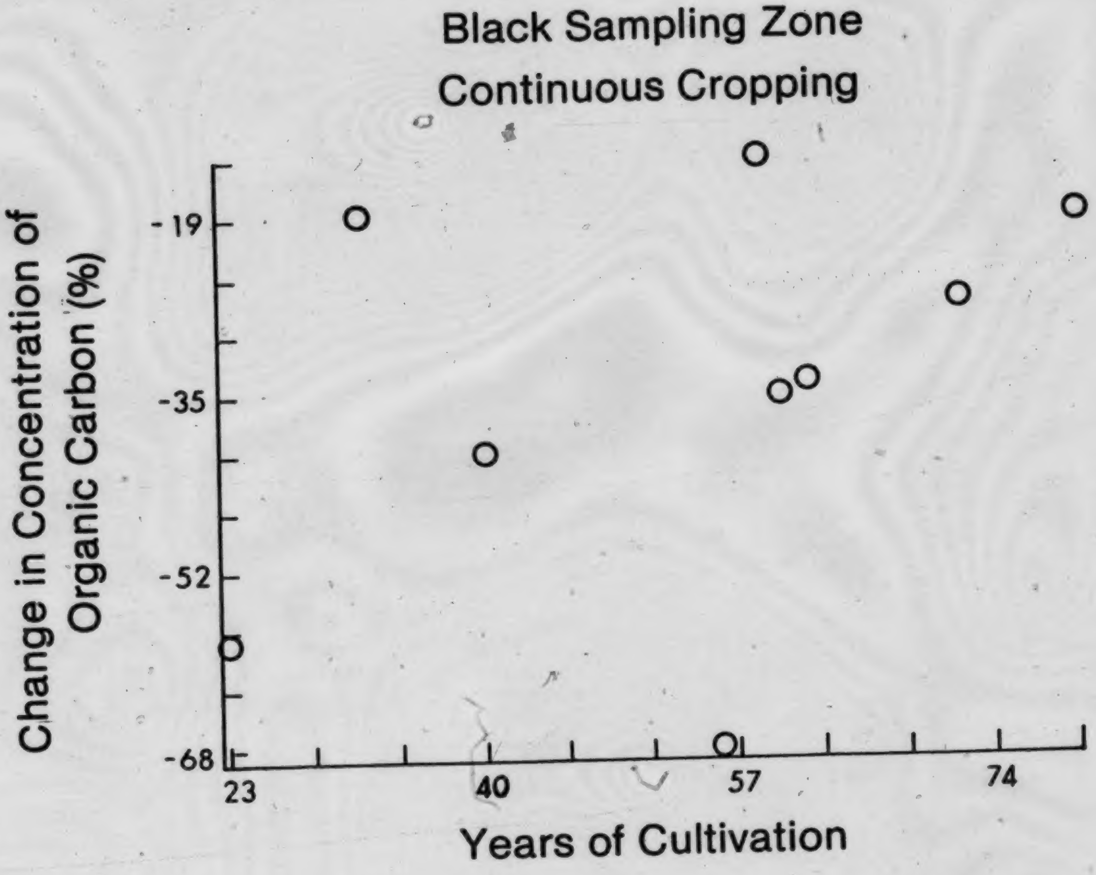

Fig.25 The Influence of Continuous Cropping on the Relationship Between Change in Concentration of Organic Carbon and Time in the Black Sampling Zone (r=0.38; p=0.16; n=9).

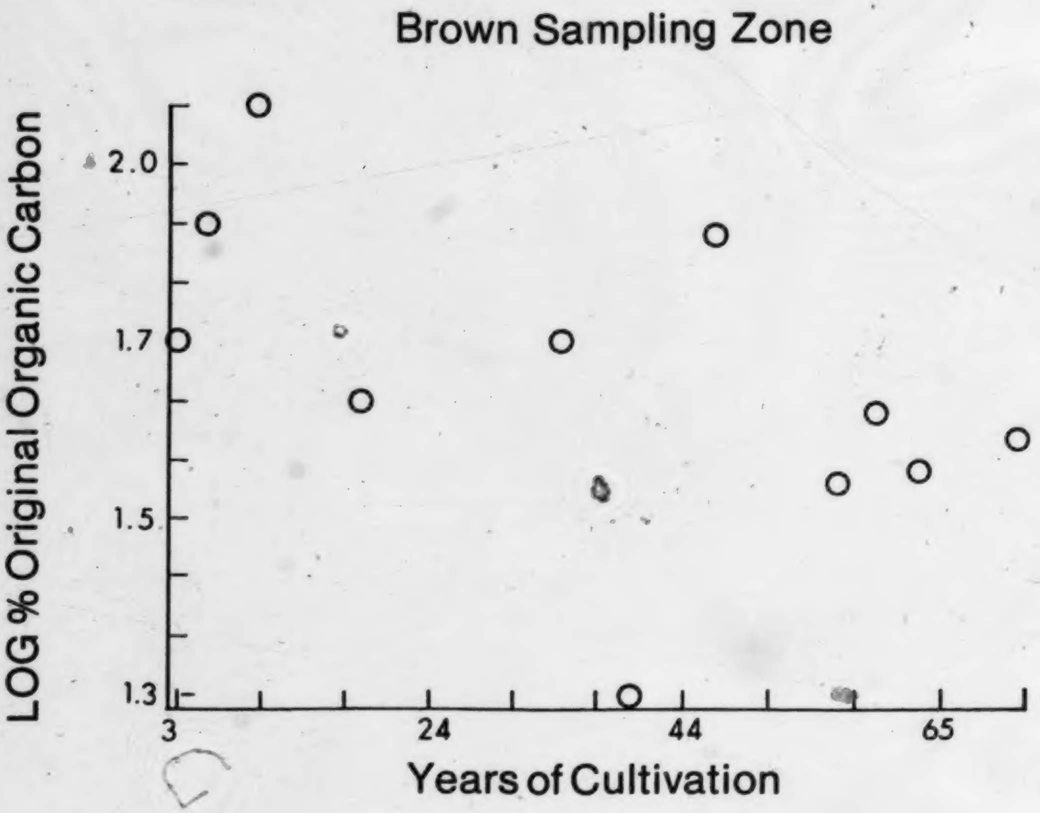

Fig.26 Relationship Between Log % of Original Organic Carbon and Time in the Brown Sampling Zone ($r=-0.51$; $p=0.06$; $n=11$).

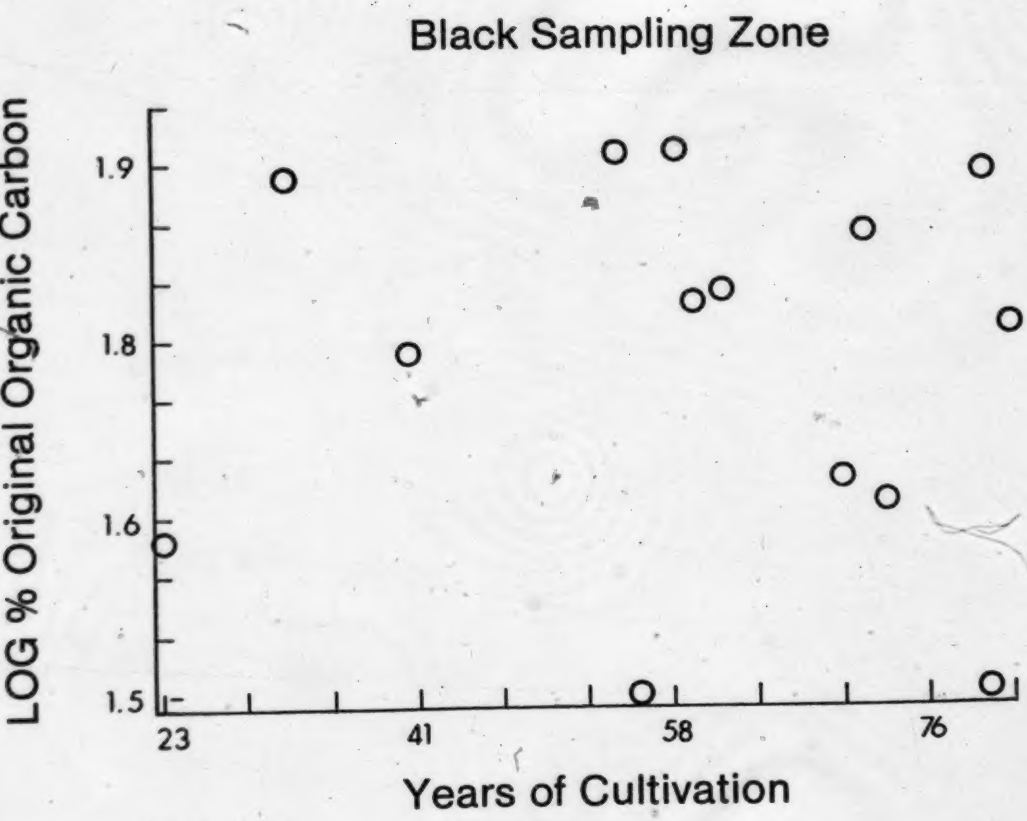

Fig.27 Relationship Between Log % of Original Organic Carbon and Time in the Black Sampling Zone (r=-0.05; p=0.43; n=14).

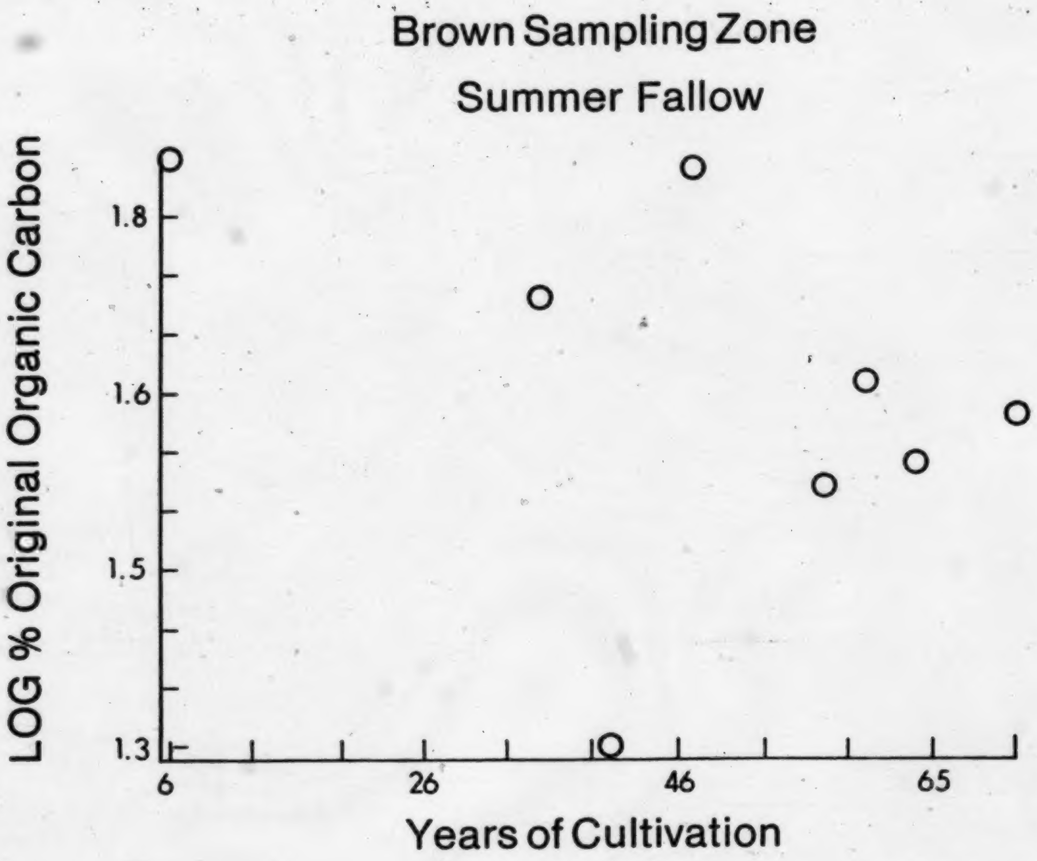

Fig.28 The Influence of Summerfallowing on the Log % of Original Organic Carbon and Time in the Brown Sampling Zone (r=-0.39; p=0.17; n=8).

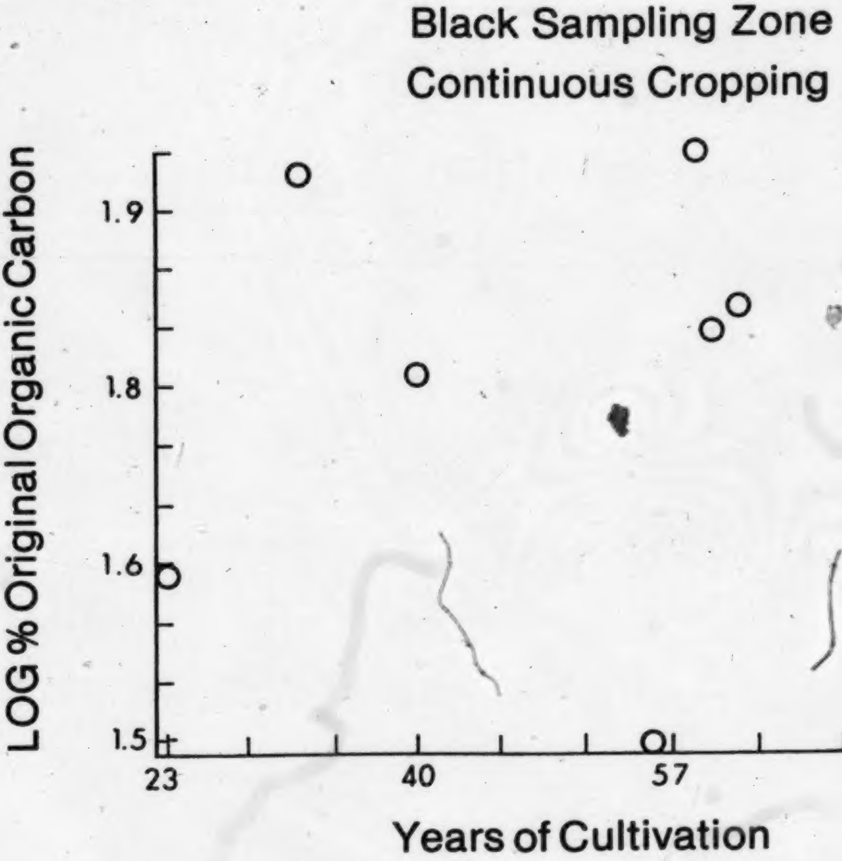

Fig.29 The Influence of Continuous Cropping on the Log % of Original Organic Carbon and Time in the Black Sampling Zone (r=0.35; p=0.18; n=9).

5.3.4 Multiple Linear Regression Models

Multiple linear regressions were performed because none of the simple linear models satisfactorily explained the relationship between observed changes in organic carbon and management variables. Three progressively more complex models were examined for each of the dependent variables listed with each set of independent variables.

First Model:

Dependent Variables:

present concentration of organic carbon
change in concentration of organic carbon
change in mass of organic carbon

Independent Variables:

original concentration of organic carbon
years of cultivation
average yield(1982-1967)
crop rotation(1982-1967)
organic residues returned(1982-1967)

Second Model:

Dependent Variables:

as before

Independent Variables:

as before except yield, crop rotation and organic residues were subdivided as follows:

average yield(1982-1977) and (1977-1967)
crop rotation(1982-1977) and (1977-1967)
organic residue returned(1982-1977) and (1977-1967)

Third Model:

Dependent Variables:

as before

Independent Variables:

as in the second model plus

density of Ap
available moisture capacity in Ap
texture of parent material (hand textured)
N input(1982-1977) and (1977-1967)
P input(1982-1977) and (1977-1967)
tillage intensity(1982-1977) and (1977-1967)

On a province level, the three models consistently yielded the same results. The change in mass of organic carbon could not be explained by any of the models. Highest prediction accuracy (r^2=0.6) for change in concentration of organic carbon was obtained with the second and third models which yielded identical results. Changes in concentration of organic carbon became more negative with higher original organic carbon content; but more positive with continuous cropping and return of organic residue.

$$Y' = -23.9 - 5.1(\text{original OC}) + 51.4(\text{crop rotation}(82\text{-}77)) -0.0005(\text{yield}(77\text{-}67)) + 2.8(\text{organic residue}(77\text{-}67));$$

n=48.

Original organic carbon explained 26% of the variability; 21% were explained by crop rotation, 9% by yield and 4% by organic residue. 40% of the variability remained unexplained.

Yields(77-67) and crop rotation(82-77) explained 43% of the variability in present concentration of organic carbon: Y'= 2.3 - 0.0004(yield(77-67)) + 2.6(crop rotation(82-77)).

Yield explained 32% and crop rotation 11% of the variability. The positive influence of continuous cropping on organic carbon content is apparent.

Table 13 summarizes the results obtained from the three models on a sampling zone level. It indicates variables taken into the regression equations, the direction of the relationship (positive slope or negative slope), and how much of the variability of the dependent variable could be explained by the variables in the equation.

As at the province level, prevailing variables taken into the regression equations were management variables and original organic carbon content. Within a sampling zone, a high degree of consistency existed between the three models with regard to the predictor variables. Between the sampling zones different management variables seemed to be linked to changes in organic carbon:

1. Brown Sampling Zone

Concentration of organic carbon decreased with increasing yields (Table 13; second model).

Table 13 SUMMARY OF RESULTS FROM MULTIPLE LINEAR REGRESSION MODELS RELATING ORGANIC CARBON(OC) CONTENT AND CHANGE TO SOIL AND MANAGEMENT VARIABLES.

Sampling Zone	Dep.Var.	First Model	Second Model	Third Model
		Independant Variables Taken into the Regression Equation		
Brown	%OC1		yield(77-67)↓ r^2=.79	
	Δ%OC	yield(82-67)↑ r^2=.56	yield(77-67)↑ r^2=.79	
	ΔmassOC		ORS↑ r^2=.57	
	# of farms	11	8	2
Dark Brown	%OC1	%OC2↑ r^2=.34	%OC2↑ r^2=.34	%OC2↑ Db↓ r^2=.82
	Δ%OC			Db↓ r^2=.51
	ΔmassOC	CRR(82-67)↑ r^2=.59	CRR(82-77)↑ r^2=.49	CRR(82-77)↑ r^2=.79
	# of farms	15	14	10
Black	%OC1		CRR(82-77)↑ r^2=.33	Yield(77-67)↑ r^2=.5
	Δ%OC			TI(82-77)↓ r^2=.63
	ΔmassOC	%OC2↑ YRS↑ CRR(82-67)↑ r^2=.89	%OC2↑ YRS↑ CRR(77-67)↑ r^2=.83	%OC2↑ r^2=.48
	# of farms	13	13	9

Table 13 (Continued).

Sampling Zone	Dep.Var.	First Model	Second Model	Third Model
		Independant Variables Taken into the Regression Equation		
Gray Luvisol	%OC1			
	△%OC	%OC2↓ r^2=.87	%OC2↓ CRR(82-77)↓ r^2=.99	
	△massOC		ORS(82-77)↑ r^2=.92	
	# of farms	6	4	3
Peace River	%OC1			
	△%OC	%OC2↓ r^2=.56	%OC2↓ r^2=.58	P(82-77)↑ ORS(82-77)↓ TPM↓ r^2=.99
	△massOC	yield(82-67)↓ r^2=.64	yield(82-77)↓ r^2=.85	yield(82-77)↓ N(82-77)↓ P(77-67)↑ ORS(82-77)↓ r^2=1.0
	# of farms	8	7	7

Dep.Var.: Dependant Variable;
OC1: present concentration of organic carbon;
△%OC: change in concentration of organic carbon;
△massOC: change in mass of organic carbon;
%OC2: original concentration of organic carbon;
Cult.time: cultivation time;
CRR: crop rotation (see codebook Appendix I);
Db:bulk density in cultivated A; N: nitrogen
ORS: organic residue (see codebook Appendix I); P: phosphorus
TI: tillage intensity
TPM:texture of parent material
↑:positive slope;
↓:negative slope;
r^2: cumulative r^2

Y' = -71.4 - 0.009(yield(82-67)); n=11; 1st model.

Y' = 0.98 - 0.0003(yield(77-67)); n=8; 2nd model.

Change in concentration of organic carbon increased with increasing yields (1st and 2nd models).

Y' = -78.8 + 0.02(yield(1977-67)); n=8; 2nd model.

Return of organic residue was positively linked with mass changes in organic carbon and explained nearly 60% of the variability (2nd model; Table 13).

2.Dark Brown Sampling Zone

Present concentration of organic carbon increased with increasing original concentration of organic carbon (1st,2nd and 3rd model). Prediction accuracy more than doubled in the third model where apparent bulk density was additionally taken into the equation.

Y' = 0.22 + 0.42(original organic carbon) - 2.2(Db cult.);
n=10; 3rd model.

Original carbon content explained 57%, apparent bulk density in the cultivated A horizons explained 25% of the variability. A strong inverse relationship between apparent bulk density and concentration of organic carbon is evident. Original organic carbon content was moderately positively correlated with crop rotations, average annual yields and N input between 1977 and 1967 (Table 14).This indirectly indicates that present concentration of organic carbon was higher when more continuous cropping and higher N input were practiced as well as higher yields achieved. Original carbon content of the soil may have been related to management

Table 14 Correlation Coefficients Between Original Concentration of Organic Carbon and Selected Management Variables

Management Variables	Original organic carbon content in sampling zones				
	Brown n=2	Dark Brown n=10	Black n=9	Gray Luvisolic n=3	Peace River n=7
Organic residue[1]			+.66		+.94
Crop rotation[2]		+.44			
Yield[2]		+.56			
N[2]		+.46			
Organic residue[2]			+.66		+.94
Cultivation time					-.62

[1]: 1982-1977
[2]: 1977-1967
n: number of cases in correlation

strategies employed.

Only the third model which took soil properties apart from concentration of organic carbon into account could explain any of the variability in change in concentration of organic carbon. Apparent bulk density explained 51% of the variability in concentration change of organic carbon. The change in concentration became more negative when bulk density increased:

$Y' = 12.8 - 44.5(\text{Db cult.})$; $n=10$.

Variability in the change in mass of organic carbon was explained consistently by crop rotation, especially five years previous to sampling (2nd and 3rd model). The positive direction of the slope indicates that the change in mass became more positive the more continuous cropping was practiced.

$Y' = -4.6 + 85.5(\text{crop rotation}(82-77))$; $n=14$; 2nd model.

$Y' = -77.8 + 24.5(\text{crop rotation}(82-77))$; $n=10$; 3rd model.

3.Black Sampling Zone

Present concentration of organic carbon increased with frequency of continuous cropping (2nd model) and when higher yields were achieved (3rd model).

Changes in concentration of organic carbon became more negative when tillage intensity increased.

$Y' = 61.3 - 28.8(\text{tillage intensity}(82-77))$; $n=9$; 3rd model.

Tillage intensity and crop rotation are not independent from each other because tillage intensity becomes higher the more summerfallowing is practiced. This indirectly indicates that summerfallowing influences changes in concentration of organic carbon negatively, whereas a practice requiring fewer tillage operations such as continuous cropping has a positive effect.

The change in mass of organic carbon became more positive the higher the original organic carbon content (1st,2nd,3rd model); the longer the cultivation time (1st and 2nd model) and the more continuous cropping was practiced (1st and 2nd model).

Y' = -153.8 + 10.6(original OC) + 1.2(years of cultivation)
+ 98(crop rotation(82-67)); n=13; 1st model.

Original organic carbon explained 54% of the variability, years of cultivation 23% and crop rotation 7%. Original organic carbon content was positively correlated with return of organic residue (Table 14). This indirectly implies that return of organic residue had a positive effect on changes in mass of organic carbon.

4. Gray Luvisolic Sampling Zone

Much of the variability in the change in concentration of organic carbon seemed to be explained by original organic carbon content whereby changes became more negative the higher the original organic carbon content (1st and 2nd model).

Y' = -19.3 - 5.1(original organic carbon); n=6; 1st model.

Some of the native profiles in this group contained LFH/Ah horizons with a high concentration of organic carbon. The dilution effect after cultivating became strongest in these cases. Correlation of original organic carbon content with management variables as seen in Table 14 and in the second model indicate that changes in concentration of organic carbon became more positive the more summerfallowing was practiced. Fields under summerfallow, however, seemed to have received high inputs of mineral fertilizer (see Table 9 and 10).

The second model indicated on the other hand, that the change in mass became more positive when more organic residue was returned. High values for organic residue coded in the Gray Luvisolic area were for input of manure and green manure in combination with lay farming. A positive change of 91% in mass of organic carbon in the A horizon was found for one site under lay rotation (Appendix II.5). Further interpretation of these data, however, is restricted due to the low number of cases in the model.

6. Peace River Sampling Zone

Close to 60% of the variability in the change in concentration of organic carbon was accounted for by original organic carbon content. Changes became more negative for sites where carbon content was originally higher. This was the case for the Gray Luvisolic soils in the Peace River area. Correlation of original organic carbon content with management variables (Table 14) implies that losses in concentration of organic carbon became higher when more organic residue was returned. Highest return of organic residue was, however, to one of the Gray Luvisolic sites;

data for the other site were missing. Considering the variety of soils in this area the number of cases is low and restricts interpretation and conclusions.

The third model indicated that P input in the five years prior to sampling had a positive effect on changes in concentration of organic carbon. Highest P input was to fields under continuous cropping (Table 10). Greater losses seemed to have occurred on soils with finer textures (3rd model)(for texture codes see Appendix I, codebook farminfo).

$Y' = -15 + 4.2(P(82-77)) - 15.2(\text{org.residue}(77-67))$

$- 6.0(\text{texture of parent material})$; $n=7$; 3rd model.

Additions of P explained 74% of the variability, organic residue an additional 20%, and texture of the parent material an additional 5%.

Changes in mass of organic carbon became more negative when higher yields were achieved (1st,2nd,3rd model).

$Y' = 147.8 - 0.05(\text{yield}(82-77))$; $n=7$; 2nd model.

They became more negative with higher input of N and organic residue (3rd model), but more positive when more P was applied (3rd model).

$Y' = 174.6 - 0.06(\text{yield}(82-77)) - 0.45(N(82-77))$

$+ 1.26(P(77-67)) - 1.3(\text{org.residue}(82-77))$; $n=7$;

3rd model.

Yield explained 85% of the variability, 14% was explained by N, 0.9% by P, and 0.1% by organic residue.

Interpretation is limited by the low number of cases together with soils of different Great Groups in this area.

5.4 Discussion

Management has changed since the late 1960s. This was mainly a reduction in summerfallowing and an increase in continuous cropping with a concomitant increase in return of organic residue and in mineral N and P input. This seemed to have been associated with an increase in yield. This is consistent with general trends in the prairie provinces as documented by Ridley and Hedlin (1980). The authors found a positive correlation between increased fertilizer input and yields. Further reasons were biological and technological progress which is difficult to assess. The historical trend reported by Ridley and Hedlin(1980) of decreasing yields due to drought and erosion in the dirty thirties with a succeeding increase in yields is not evident from the data of this study. A more thorough survey necessary for such a purpose was not within the scope of this thesis.

Average annual cereal yields in the 15 years previous to sampling were 1.6(if the one farm with continuous cropping is eliminated), 1.7, 2.3, 1.8 and 2.1 Mg ha^{-1} in the Brown, Dark Brown, Black, Gray Luvisolic and Peace River zones (Table 11). They were 1.6, 2.3, 1.7 and 2.2 Mg ha^{-1} for the Dark Brown, Black, Gray Luvisolic and Peace River zones between 1977 and 1967 (Table 11). Average cereal yields in Alberta based on 1966-1974 Alberta Hail and Crop Insurance Corporation records were 1.7, 2.3, 2.4, 1.6 and 1.5 Mg ha^{-1} in the Brown, Dark Brown, Black, Gray Luvisolic and Peace River zones. These data were calculated from

Tables D1 to D15 of Peters and Pettapiece(1981). Data of the present study seem to underestimate yields in the Dark Brown zone and overestimate yields in the Gray Luvisolic and Peace River zone. A comparatively low number of cases was available in this study, but data do not diverge markedly from provincial averages obtained from Peters and Pettapiece(1981) using a much larger data base. These data suggest the sampling of farm units was not biased toward any group of farmers.

The change to continuous cropping affected more the central and northern regions of the province as indicated by the present percentage of summerfallowing in the various sampling zones. Similar trends were reported by Anderson & Associates Ltd.(1981). Factors explaining summerfallow frequency in their study were mainly debt-equity ratios and land-factor cost ratios. Pre-season moisture, weed control and energy conservation played a subordinate role. The authors indicated that summerfallowing could be a very rational practice from a private point-of-view on coarser drier soil in southern regions of the province. They further concluded that economic benefits from summerfallowing were short-run and accrued directly to farmers whereas many of the costs were long-run and accrued to society. Such socio-economic costs are salinity problems, erosion and, linked to it, organic matter loss.

Statistical analysis at the sampling zone level yielded a higher resolution than was possible at the province level, indicating regional aspects are important.

None of the simple linear models fully explained the variability in present concentration of organic carbon and in changes in concentration and mass of organic carbon with time. This was not unexpected as the present models on organic carbon dynamics suggest a continuous decline in organic matter with time according to a first order reaction.

A curvilinear trend for declining soil organic carbon with time which is in agreement with existing models appeared to be present only for the change in concentration of organic carbon in the Brown sampling zone. For the remaining zones, as well as for the whole province, there was no evidence of a consistent continuing decline in organic carbon with time, but some evidence of a positive trend. This suggests that although organic carbon has decreased since cultivation started, as shown in the previous chapter, there might be an increasing trend at present. This was supported by results from loglinear tranformations, and is consistent with changes in cropping systems during this century.

Multiple linear regression models indicated that positive changes in concentration and mass of organic carbon were related to higher yields and return of organic residue in the Brown sampling zone; they were related to continuous cropping in the Dark Brown sampling zone. Mass changes in the Black sampling zone were positively related to original concentration of organic carbon, years of cultivation and continuous cropping. In the Gray Luvisolic and Peace River regions, however, changes in concentration and mass were negatively influenced by original concentration of organic carbon. This shows the effect of the rapid loss from LFH material on the one hand and slower loss of Ah material on the other. Such observations are consistent with the hypothesis that association with mineral particles in the Ah horizon provides physical protection to organic carbon.

Whereas continuous cropping, higher yields and increased return of organic residue had positive effects on changes in organic carbon in the Chernozemic zones, it seemed to have the opposite effect in the Peace River and Gray Luvisolic zones. Although interpretation is restricted by a low number of cases in the Luvisolic zone and a range of Great Groups in the Peace River zone, this indicates that the original nature of the soil determines its reaction to management practices. The rapid loss from LFH material seems to have an overriding effect on ameliorative practices like return of organic residue in the Peace River zone. The residues were added to the site most susceptible to loss and dilution. The loss of organic carbon with more residues in the Peace River area was therefore only a correlation and not an effect. Linear regression models do not describe these complex relationships.

On a provincial level, the change in concentration of organic carbon was negatively influenced by original organic carbon content and yield; this suggests the influence of the Peace River area. They were positively affected by continuous cropping and organic residue indicating an influence of the Chernozemic zones. The negative effect of yield is likely related to the fact that yield was reported and used for the year obtained and not as annual yield. Consequently, fallow systems may have highest yield in the non-fallow year but lowest annual yield. which then shows up as a negative yield effect. Therefore, such methods of increasing yields are destructive of organic matter.

Table 14 suggests a relationship between original organic carbon content and management practices employed. This relationship might reflect the capability of the soil for crop production. Similar trends were reported by Reinl(1981). Original concentration of organic carbon reflects a specific combination of soil forming factors such as climate or parent material which are likely to influence management decisions.

Statistical analysis in this section dealt only with data from the last 15 years prior to sampling. Too many data from 1967 to 1907 were missing to allow statistical analysis. The data base indicates, however, that changes in management occurred mainly during these last 15 years previous to sampling. The main changes are a substitution of summerfallow rotations by continuous cropping with a concomitant increase in the amount of input of mineral fertilizer and straw return. This might be linked to the observation that no consistent continuing decline in organic carbon over time was evident and to the hypothesis of a trend toward increasing organic matter following an initial decline. The fact that higher losses occurred under summerfallow than under continuous cropping is consistent with the above hypothesis. Rotation studies have shown that continuous cropping is less destructive to soil organic matter than is summerfallowing. This is due mainly to the increased input of belowground residues. Steady-state levels of organic matter are determined by the ratio of addition to removal rates. An increase in addition rate will cause a proportional increase in the steady-state quantity if removal rate remains constant. A change to a management system with a higher ratio of addition rate to removal rate will therefore cause organic carbon to increase toward a higher steady-state level. Existing mathematical models of organic matter dynamics treat management as constant over time. The present study has shown that inputs of organic residue have increased since cultivation started and are not constant with time. Therefore, the addition term (R) in these models must be modified to describe the present situation.

5.5 Conclusions

Management practices changed since the late 1960s. Since then continuous cropping with concomitantly higher straw return and input of N and P has replaced summerfallowing especially in the central and northern regions of the province. Increases in yield took place in the same period especially under continuous cropping. Losses in organic carbon tended to be lower under continuous cropping than under summerfallow.

No simple linear model could explain the variability in organic carbon changes with time. A higher level of resolution was reached at the regional than at the provincial level.

There is no evidence of a consistent continuing decline of organic carbon with time. This holds for the whole province as well as for the sampling zones. Only in the Brown sampling zone, was a negative curvilinear trend evident for changes in concentration of organic carbon with time. In the remaining sampling zones no such trend was obvious. This was supported by results from loglinear transformations.

Multiple linear regression models indicated that the change in organic carbon was positively related to continuous cropping, yields and original organic carbon content in the Brown, Dark Brown and Black sampling zones. Interpretation was limited for the Gray Luvisolic and Peace River area due to low number of cases. The linear treatments indicated, however, that the effect of continuous cropping, organic residue and yields in the Chernozemic zones was opposite to that in the Luvisolic and Peace River zones. This seemed to be related to the original nature of the soil in these areas. Loss of organic carbon with ameliorative practices was therefore a correlation, not an effect.

Changes in management in the last 15 years previous to sampling seem to have reversed the direction of organic carbon changes toward a higher steady-state level.

6. Overall Summary and Conclusions

Significant changes in organic carbon have resulted from cultivation in Alberta. On the sampling zone level, changes were negative. Concentration of organic carbon in cultivated A horizons decreased by 52%, 42%, 40%, 13%, 75% and 64% in the Brown, Dark Brown, Black, Dark Gray, Gray Luvisolic and Peace River sampling zones. Mass in the A horizon decreased by 31%, 28%, 17%, 29%, 27% and 15% for the same sampling zones. Mass in the profile decreased by 36%, 25%, 21%, 22%, 39% and 28% in these sampling zones. At the individual farm level, however, some positive changes in mass of organic carbon occurred: 21%, 13%, 33%, 43% and 42% of the sites in the Brown, Dark Brown, Black, Gray Luvisolic and Peace River sampling zones had a gain in mass of organic carbon in the A horizon. A mass gain in the profile occurred on 14%, 13%, 14% and 33% of the sites in the Brown, Black, Gray Luvisolic and Peace River area. These farms were viable units. One must conclude,therefore, that it is possible to increase organic matter and maintain a viable farm operation. The financial aspect of this merits further detailed investigation.

The estimate of McGill et al(1981) of a 35%-50% organic matter loss on the Canadian Prairies lies within the range of concentration and mass losses but tends to be higher than those found here. Data reported in the literature on organic matter loss correspond with 14% of the farms in the Brown and 17% of those in the Dark Brown sampling zones in the present study under similar crop rotation and cultivation time. Most literature values are derived from only one to three sites, however. They can not appropriately represent the average for any soil zone. A larger number is needed than has been used in the past.

Loss in concentration tended to be higher than losses in mass. This can be attributed to dilution resulting from subsurface horizon material being mixed into the A horizon. The thickness of A horizons increased in cultivated profiles, though not significantly; B horizon thickness tended to decrease. Linked to this was an increase in apparent bulk density. An inverse relationship was found between changes in apparent bulk density and changes in concentration of organic carbon.

Moisture retention at -33 and -1500kPa in A horizons decreased due to cultivation. The effect was greater at lower potentials than at higher potentials with the result that available moisture capacity increased due to cultivation.

No reduction in profile depths occurred upon cultivation suggesting no major erosion effects on organic matter losses. Variability in profile thicknesses causes such a measure of erosion to have a low resolution, however, and a definitive answer to the relation between erosion and decomposition awaits further study.

Simple linear regressions and log transformations indicated that there was no consistent decline in organic carbon with time over the whole province nor in individual sampling zones. Only the change in concentration of organic carbon with time in the Brown sampling zone showed the negative curvilinear trend embodied in existing concepts. There is a possibility that losses have ceased. This seemed to be linked to changes in management practices during the last 5 to 15 years previous to sampling in 1982. During that time continuous cropping with more straw return and application of mineral fertilizer became more frequent. Yields increased simultaneously, mainly under continuous cropping.

Multiple linear regression analyses suggested that present higher concentrations of organic carbon and changes in concentration and mass of organic carbon were positively influenced by continuous cropping and yields in the Brown, Dark Brown and Black sampling zones. The lowest loss in organic carbon in the Black sampling zone therefore seems to be related to the highest frequency of continuous cropping and highest average yields in the last 15 years previous to sampling. The Brown sampling zone on the other hand had the highest proportion of summerfallow and highest proportional loss of organic carbon of the Chernozemic zones. Interpretation of data for the Gray Luvisolic and Peace River area was limited due to small sample size. The models indicated, however, that the soils in these regions reacted opposite to the soils in the Chernozemic areas when under the same management. This might be related to the original nature of the soil. It shows the effect of the rapid loss from LFH material as opposed to physical protection of organic carbon when associated with mineral particles in Ah horizons. This rapid loss had an overriding effect on ameliorative practices like returning of organic residues.

Results for the Brown, Dark Brown and Black zones suggest that change in management to continuous cropping together with higher input of mineral fertilizer has reversed the direction of changes in organic carbon. This is consistent with the literature from rotation studies. It has never before been shown at the farm level. Losses of organic carbon under continuous cropping were lower than under summerfallow in the Brown, Dark Brown and Black sampling zones.

Some of the above trends were not statistically significant, however. This could be due to insufficient sample size per sampling zone even though this study is the most thorough yet reported in the literature. Data obtained are the first data base derived from farm sites on a broad geographic, climatic , soil and management base. Existing data which are the basis for present theoretical models were derived from few sample sites, research plots or lab experiments. Data of this study may be used in testing existing theoretical models. These models will have to be reviewed to provide a linkage for the above findings. Mathematical models have up to now treated management as a constant and organic carbon decreased continuously in a series of first order reactions to lower levels than found here. Results of this thesis have shown that changes in management do occur and can reverse changes in organic carbon. Mathematical models should therefore be modified to accommodate such changes in management and their effects. Modifications with regard to changing inputs of organic residues with time would make the present models more consistent with the results of the present study.

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7. APPENDIX I

Sample Questionnaire

Codebook for File Farminfo

Codebook for File Cropinfo

Codebook for File Analysis: Labanalysis Data

QUESTIONNAIRE

Name:
Address:
Legal Location:
Soil Zone:
Soil Classification:
Total time cultivated years:

Cropping systems since beginning of cultivation:

Year Cropping system

....
....
....
....
....
....
....
....

Application of chemical fertilizer:

Year Amount of N P K S Lime

....
....
....
....
....
....
....

Organic residue returned:

Year ....
Straw removed ....
Stubble Mulch ....
All Straw Returned ....
Manure ....
Green Manure ....

Tillage operations during:

Cropping systems:

Fallow:

Weed Control:

chemical

mechanical

cultural

Yields:

Year ....
Wheat ....
Barley ....
Oats ....
Canola ....
....
....
....
....

How would you rate erosion effects since cultivation started?

severe?......... light?..............

moderate?........ negligible?.........

Dominant type of erosion: wind....... water.......

Did you notice any changes in organic matter content?

No...... If yes, which? ....

Did you notice any changes in:

Tilth: No ...... If yes, which? ....

Water Storage: No .... If yes, which? ....

Nutrient Supply: No ...... If yes, which? ....

What are your future management plans? ....
....
....

Codebook for File Farminfo

Col 1- 2: Farm-ID	01 - 80
Col 4: Land use	1=cultivated 2=native
Col 6-14: Legal location	1=NW 2=NE 3=SE 4=SW 5=centre Section=01-36 Township=01-120 Range=01-30 Meridian 4=W4 5=W5
Col 16: Soil order	1=Brunisolic 2=Chernozemic 3=Gleysolic 4=Luvisolic 5=Organic 6=Podzolic 7=Regosolic 8=Solonetzic 9=undefined
Col 18-19: Great group	1=Melanic Brunisol 2=Eutric Brunisol 3=Sombric Brunisol 4=Dystric Brunisol 5=Brown 6=Dark Brown 7=Black 8=Dark Gray 9=Humic Gleysol 10=Gleysol 11=Luvic Gleysol 12=Gray Luvisol 13=Fibrisol 14=Mesisol 15=Humisol 16=Humo Ferric Podzol 17=Regosol 18=Humic Regosol 19=Solonetz 20=Solodized Solonetz 21=Solod 99=undefined
Col 21-24: Subgroup	1=alkaline 2=black

		3=brown 4=brunisolic 5=calcareous 6=cumulic 7=dark 8=dark brown 9=dark gray 10=eluviated 11=ferric 12=fera 13=gleyed 14=gray 15=humic 16=orthic 17=podzolic 18=rego 19=solonetzic 20=typic 99=undefined
Col 26-28:	Series	999=undefined
Col 30-31:	Ecoregion	99=undefined
Col 33-34:	Physiographic section	99=undefined
Col 36:	Agroclimate	1=Rainfall adequate;>90 days frost-free 2=Rainfall limiting 50% of vegetation time; >90 days frost-free 3=Rainfall limiting; >100 days frost-free 4=Rainfall adequate; 75-90 days frost-free 5=Rainfall adequate; 60-75 days frost-free 6=Rainfall adequate; <60 days frost-free 7=Mountain complex; precambrian shield
Col 38:	Soil Capability	1=land has no significant limitations in use for crops adapted to area 2,3=moderate to moderately severe limitations that restrict range in crops or require special conservation practices; land is good to

fair for agricultural production
4=severe limitations, range of crops restricted, special conservation practices; marginal for sustained cereal crop production; low productivity for wide range of crops or good productivity for restricted range
5,6=severe limitations, restricted capability to production of perennial forage crops or native pasture
7=no capability for arable agricultural or permanent pasture
9=undefined

Col 40-41: Landform
1=apron
2=delta
3=fan
4=lake plain
5=hummocky
6=inclined
7=level
8=ridged
9=rolling
10=terraced
11=undulating
99=undefined

Col 43: Parent Material
1=glaciofluvial
2=glaciolacustrine
3=aeolian
4=fluvial
5=lacustrine
6=colluvial
7=organic
8=till
9=undefined

Col 45: Texture of parent material
1=coarse sand
2=medium sandy
3=fine sandy
4=sandy loam
5=silty loam
6=clayey loam
7=silty
8=clayey

9=organic
0=undefined

Col 47-53: Color of A horizon Hue: 1=10YR 2=2.5YR
3=7.5YR 4=5Y 5=5G
Value: as determined
Chroma: as determined

Col 55-56: Years of cultivation as determined

Col 58: Erosion type
1=wind
2=water
3=both
0=no erosion Col 59-60:
Erosion extent
col 59: overall
col 60: hilltop
1=severe
2=moderate
3=light
4=negligible
0=no erosion

Col 62: Noticed changes in organic matter
1=strong loss
2=medium loss
3=light loss
4=gain
5=no changes
0=native

Col 64: Noticed changes in tilth
1=no
2=yes, improved
3=yes, deteriorated

Col 66: Noticed changes in water storage
1=no
2=yes, improved
3=yes, deteriorated

Col 68: Noticed changes in nutrient supply
1=no
2=yes, improved
3=yes, deteriorated

Col 70-75: Future Management 01=more fertilizer

Codebook for File Cropinfo

File cropinfo contains 5 records per farm;the 5 lines represent different years:

1: 1982-1978
2: 1977-1967
3: 1966-1947
4: 1946-1927
5: 1926-1907

Col 1- 2: farm ID

Col 4: crop rotation: 1=crop-summerfallow; 2=crop-crop-summerfallow;3=continuous cropping;4=continuous pasture; 5=lay farming;6=native;9=missing

Col 6: main crop in the system: 1=cereal; 2=forage; 3=oil crop; 4=legume; 6=native; 9=missing

Col 8-11: average yield of main crop for specified years(kg/ha)

Col 13: second crop in system

Col 15-18: average yield of second crop(kg/ha)

Col 20: organic residue returned; 1=straw baled; 2=straw burnt 3=stubble mulch; 4=manure; 5=green manure; 6=all straw returned; 7=native; 9=missing

Col 22-25: N fertilizer (kg/ha)

Col 27-30: P (kg/ha)

Col 32-35: K (kg/ha)

Col 37-40: S (kg/ha)

Col 42: Tillage intensity: 1=Zero; 2=minimum;

3=conventional; 4=excessive; 6=native; 9=missing

Col 44: Weed control: 1=chemical; 2=mechanical;
3=cultural; 6=native; 9=missing

Codebook for File Analysis: Labanalysis Data

Col 1- 2: Farm-ID 0 - 80

Col 4: Horizon
1=Ap/Ah
2=Ae
3=AB
4=B
5=BC
6=C

Col 6- 7: Replicate
01-05=cultivated
06-10=native

Col 9-15: Weight(g)

Col 17-20: Depth(cm)

Col 22-25: Compaction(cm)

Col 27-29: pH

Col 31-33: Inorganic carbon(%)

Col 36-39: Total carbon(%)

Col 41-44: Organic carbon(%)

Col 46: Slope position
1=crest
2=upper
3=mid
4=lower
5=toe
6=depression
9=undefined
0=no slope

Col 48-51: Moisture retention(%) at 1/3 bar

Col 53-56: Moisture retention(%) at 15 bar

Col 58-61: % available moisture

8. APPENDIX II

Summary Results of Cultivated and Native Sites by Farm in the Sampling Zones.

Each row of data represents a separate farm.

* indicates differences at the 5% significance level between cultivated and native sites.
** indicates differences at the 1% significance level between cultivated and native sites.

Appendix II.1 BROWN SAMPLING ZONE

Average concentration and mass of organic carbon in cultivated and native A horizons

Concentration of Organic Carbon(%)		Mass of Organic Carbon(kg·ha⁻¹)	
CULTIVATED	NATIVE	CULTIVATED	NATIVE
2.2± .4	2.1± .4	29 739 ± 5 727	37 770 ± 7 234
1.3± .3**	6.2±2.5	25 843 ± 6 404	36 121 ±14 414
1.3± .6**	3.5±1.2	21 483 ± 9 707	29 060 ± 9 789
1.3± .5	2.8±2.3	25 283 ± 9 520	44 885 ±37 059
1.1± .2*	2.0± .5	27 244 ± 4 301	27 174 ± 7 454
1.6± .1*	2.2± .7	25 112 ±11 246	29 021 ±11 016
1.4± .1**	2.4± .5	22 435 ±22 436	57 661 ±12 713
1.2± .4**	2.9± .7	23 190 ± 7 532	40 333 ±10 029
1.1± .4**	2.4± .6	23 906 ±10 162	52 221 ±14 476
1.5± .5	2.0± .6	22 770 ± 7 967	18 347 ± 5 361
1.7± .1**	3.1± .5	32 110 ± 2 476	46 731 ± 7 292
1.4± .4	3.6±1.7	25 778 ± 5 966	63 344 ±30 937
1.1± .1**	2.1± .3	22 947 ± 2 295	24 561 ± 3 698
1.4± .2	3.3±3.3	36 327 ± 5 707	26 449 ±26 576
1.4± .3**	2.9±1.1	26 012 ± 4 169**	38 120 ±13 421

Change in Concentration of OC(%)	Change in Mass of OC(%)
.93	-21
-79	-28
-63	-26
-53	-44
-47	+.3
-29	-13
-43	-61
-58	-42
-55	-54
-25	24
-44	-31
-61	-59
-46	- 7
-58	+37

Appendix II.1 (Continued).

Average Mass and Change in Mass of Organic Carbon in Cultivated and Native Profiles

Mass of Organic Carbon(kg·ha^{-1})		Change in Mass of Organic Carbon(%)
Cultivated	**Native**	
47 455 ± 6 823	50 742 ± 12 711	- 7
40 495 ± 6 156	70 491 ± 33 247	-43
31 364 ± 7 703	60 148 ± 19 259	-48
60 608 ±25 452	44 885 ± 37 058	+35
39 934 ±11 441	55 570 ± 17 863	-28
39 252 ±11 548	49 038 ± 11 365	-20
34 146 ± 2 657	73 625 ± 13 945	-54
37 182 ±11 761	79 208 ± 15 069	-53
46 972 ±19 781	125 290 ±110 001	-62
32 947 ± 9 887	38 053 ± 10 976	-13
58 119 ± 7 963	84 971 ± 15 336	-32
46 158 ± 7 831	93 484 ± 61 054	-51
32 869 ±12 153	72 558 ± 16 524	-55
68 781 ±30 981	63 424 ± 36 061	+ 8
44 020 ±11 487**	68 678 ± 22 741	

Appendix II.1 (Continued).

Average Thickness(cm), pH, Apparent Bulk Density(Db)($Mg.m^{-3}$),Available Moisture Capacity(AW)(%), and Moisture Retention at -33(FC) and -1500kPa(PW)(%)in Cultivated A Horizons

Thickness	pH	Db	AW	FC	PW
12.2±5.6	7.1±0.4	1.1±0.1	11.1±0.4	25.4±0.8	14.3±0.5**
14.0±1.7	6.3±1.4	1.4±0.2**	10.7±1.4		7.4±1.0
13.3±5.0	6.8±0.5	1.2±0.2*	12.5±1.0	22.9±2.6*	10.4±2.1*
15.5±4.9	6.6±0.3	1.2±0.1	5.5±0.3**	12.0±0.0	6.1±2.0
18.7±1.8	7.5±0.4	1.6±0.1	11.6±1.7	21.6±3.5	10.1±2.2
12.3±0.6	7.5±0.3**	1.3±0.2	15.2±0.6**	39.4±0.7**	24.3±0.3**
12.3±1.7	7.3±0.3	1.3±0.1	11.2±0.9		13.6±1.7
15.0±1.0	6.3±1.5	1.3±0.1	15.0±2.8	26.4±7.2	11.4±2.0
14.7±5.0	6.4±0.9	1.5±0.1	6.1±1.3	14.2±7.2	8.1±6.0
11.8±1.3**	7.6±0.4**	1.3±0.3	11.2±2.3	26.4±6.6	15.2±5.9
13.0±1.3	6.6±0.2*	1.4±0.1**	13.4±0.5*	25.3±1.0*	11.8±1.2**
12.8±2.7	6.3±0.7	1.5±0.1**	7.4±1.1	14.2±1.6	6.8±0.6
13.7±1.4	7.6±0.3*	1.5±0.2	10.4±0.7**	23.4±0.5	12.9±0.8*
15.3±2.8*	7.5±0.9	1.7±0.2	13.7±1.2	25.3±4.5	11.6±4.2
13.9±1.9	6.9±0.5*	1.4±0.2*	11.1±3.3**	23.1±8.9	11.9±4.8

Average Thickness(cm), pH, Apparent Bulk Density(Db)($Mg\cdot m^{-3}$),Available Moisture Capacity(AW)(%), and Moisture Retention at -33(FC)and -1500kPa(PW)(%)in Native A Horizons

Thickness	pH	Db	AW	FC	PW
15.0±3.6	6.9±0.3	1.2±0.1	9.9±0.9	26.7±1.2	16.8±0.3
10.5±7.4	5.4±0.3	0.6±0.2			
9.0±2.6	6.3±0.3	0.9±0.1	14.1±1.1	29.6±2.6	15.5±1.5
13.5±5.1	6.8±0.2	1.1±0.3	3.1±0.6	11.6±2.6	8.5±2.0
11.8±4.4	7.0±0.8	1.4±1.1	12.1±2.0	24.5±1.4	12.4±3.4
11.2±2.3	6.6±0.4	1.1±0.0	11.5±1.2	25.2±1.7	13.7±1.2
14.6±3.0	7.2±0.5	1.5±0.6			
11.2±4.0	6.6±0.7	1.3±0.1	13.3±4.3	24.8±5.8	11.4±3.1
16.7±7.9	5.9±0.3	1.3±0.1	4.6±1.1	13.8±1.7	9.2±0.8
6.0±1.7	6.9±0.2	1.6±0.2	9.7±0.7	20.8±2.1	11.2±1.7
13.5±2.5	7.0±0.3	1.1±0.0	12.2±0.1	28.4±0.6	16.2±0.4
16.7±2.9	6.1±0.5	1.1±0.1	6.0±2.1	21.5±9.7	15.5±8.7
9.7±6.3	7.1±0.3	1.2±0.1	8.1±0.5	24.1±0.6	16.0±1.0
6.0±4.4	7.3±0.5	1.2±0.5	14.1±2.9	26.8±0.9	12.7±2.6
11.8±3.4	6.7±0.6	1.2±0.3	10.0±3.8	23.4±5.7	13.5±2.9

Appendix II.1 (Continued).

Average Concentration of Organic Carbon(OC%), Average Horizon Thickness(HT)(cm), pH and Apparent Bulk Density(Db)($Mg \cdot m^{-3}$) in Cultivated and Native Profiles.

Horizon	OC	HT	pH	Db
Ap	1.4±0.3	13.9±1.9	6.9±0.5	1.4±0.2
B	0.8±0.4	15.7±5.5	7.6±0.6**	1.5±0.3
Ah	2.9±1.1	11.8±3.4	6.7±0.6	1.2±0.3
B	1.1±0.4	17.2±5.8	7.1±0.6	1.4±0.1

Appendix II.2 DARK BROWN SAMPLING ZONE

Average concentration and mass of organic carbon in cultivated and native A horizons

Concentration of Organic Carbon(%)		Mass of Organic Carbon($kg \cdot ha^{-1}$)	
CULTIVATED	NATIVE	CULTIVATED	NATIVE
1.6±0.0**	2.8±0.0	29 007± 3 668	46 179± 5 434
3.2±0.0**	4.7±0.0	98 451±12 959	106 788±15 783
3.4±1.0**	6.6±0.7	50 467±14 624	91 224± 9 321
1.9±0.7**	4.2±1.1	71 749±26 230	107 013±29 823
3.8±0.9**	6.7±1.1	56 852±13 431	58 315± 9 866
3.9±0.8	4.4±1.2	42 964± 9 078	51 125±14 317
2.5±0.6	3.5±0.9	35 944± 8 928	34 921± 8 701
1.7±0.3**	5.2±0.9	19 497± 8 306	36 578±21 118
1.7±0.5*	4.8±1.9	28 528± 5 622	51 896± 4 766
2.7±2.7**	4.7±0.5	35 065± 5 622	44 240± 4 766
2.5±0.9**	4.5±1.2	34 027±11 903	75 464±19 754
2.6±0.4**	4.8±0.5	39 618± 6 712	59 131± 5 951
2.4±0.7**	4.5±1.2	37 755±10 606	48 058±12 679
3.9±0.8	5.7±1.7	56 427±11 793	82 094±24 014
2.4±0.3	3.7±1.5	56 668± 7 083	52 187±20 474
2.3±0.2**	4.1±0.2	20 775± 2 269	53 256± 2 962
2.7±0.8**	4.7±1.0	44 612±20 262**	62 404±23 127

Change in Concentration of OC(%)	Change in Mass of OC(%)
-41	-37
-33	- 8
-49	-44
-54	-33
-43	- 2
-11	-16
-28	+ 3
-67	-47
-65	-45
-42	-21
-43	-55
-45	-33
-47	-21
-31	-31
-35	+ 9
-45	-61

Appendix II.2 (Continued).

Average Mass and Change in Mass of Organic Carbon in Cultivated and Native Profiles

Mass of Organic Carbon(kg·ha^{-1})		Change in Mass of Organic Carbon(%)
Cultivated	Native	
41 932 ± 6 603	81 890 ±14 446	-49
127 486 ±27 061	152 506 ±17 949	-16
84 938 ±21 246	134 158 ±20 974	-37
100 326 ±43 850	135 415 ±26 047	-26
105 615 ±35 434	107 044 ±13 943	- 1
112 194 ±65 697	81 714 ±18 192	-37
60 020 ±13 202	76 608 ±12 036	-22
48 234 ±13 812	90 323 ±21 964	-47
49 444 ±14 504	91 977 ±25 014	-46
85 668 ±23 464	91 354 ±18 733	- 6
69 253 ±35 053	121 289 ±24 554	-43
93 613 ±40 858	124 372 ±15 719	-25
72 433 ±37 023	96 626 ±43 208	-25
92 267 ±34 689	143 026 ±46 271	-35
81 095 ±11 338	92 812 ±18 296	-13
51 048 ± 6 591	87 768 ± 5 399	-42
79 723 ±25 239**	106 805 ±24 549	-25

Appendix II.2 (Continued).

Average Thickness(cm), pH, Apparent Bulk Density(Db)($Mg \cdot m^{-3}$),Available Moisture Capacity(AW)(%), and Moisture Retention at -33(FC) and -1500kPa(PW)(%)in Cultivated A Horizons

Thickness	pH	Db	AW	FC	PW
13.3±1.2	5.9±0.3	1.3±0.2	10.5±0.8	23.1±0.4	12.7±1.1
26.7±16.0	5.9±0.4	1.3±0.3	12.5±1.2	27.1±2.3	14.6±1.8
12.5±4.1	5.6±0.5	1.2±0.2*	12.5±2.5	28.0±5.5	15.5±3.6
26.5±4.4	5.8±0.2	1.4±0.1	7.9±1.9	13.9±4.1	7.9±1.3
14.0±7.3	6.0±0.2	1.1±0.1	18.7±2.8	33.3±6.4	14.5±4.2
10.5±1.8*	6.1±0.2	1.0±0.2	16.0±5.8	32.7±6.3	16.7±1.1
13.5±4.0	6.4±0.4	1.0±0.2	14.2±2.5	28.6±4.7	14.3±2.3
11.7±3.8	6.6±0.7	1.0±0.5	11.8±4.7	32.3±14.9	20.4±10.3
11.2±1.9	6.3±0.9	1.5±0.1**	13.2±0.7	25.1±1.9	11.9±1.3
10.7±2.0	5.7±0.4	1.2±0.2	10.8±0.6	27.0±2.0*	16.2±1.8
9.3±6.2	5.3±0.2*	1.5±0.2*	12.5±3.5	21.4±6.7*	8.9±3.2
14.3±4.5	5.5±0.3	1.0±0.1	17.5±0.8**	28.9±1.7	11.4±1.6
11.8±1.9	7.6±0.2	1.4±0.2	7.7±2.0	18.8±4.2	11.1±2.1
13.3±3.2	5.3±0.2	1.1±0.1	12.9±1.3	36.6±1.3	23.7±1.8
17.3±4.5	6.2±0.1*	1.3±0.1**	15.2±1.6**	27.0±1.9	11.8±0.3
8.0±1.7*	7.5±0.2**	1.1±0.1			
14.0±5.3	6.1±0.7	1.2±0.2	12.9±0.3**	26.9±5.9**	14.1±4.1**

Average Thickness(cm), pH, Apparent Bulk Density(Db)($Mg \cdot m^{-3}$),Available Moisture Capacity(AW)(%), and Moisture Retention at -33(FC) and -15kPa(PW)(%) in Native A Horizons

Thickness	pH	Db	AW	FC	PW
14.2±0.7	6.0±0.2	1.2±0.1	10.0±0.1	24.1±2.7	14.1±2.6
22.3±16.8	5.6±0.4	0.9±0.1	12.1±1.4	30.1±2.2	17.9±0.9
16.0±4.1	5.6±0.2	0.9±0.0	11.5±0.3	35.7±0.6	24.2±0.3
22.0±1.7	5.8±0.2	1.1±0.1	6.0±2.3	21.5±6.2	15.5±4.2
9.7±3.2	6.3±0.5	0.9±0.2	15.8±1.8	46.4±7.3	30.7±6.1
13.8±1.0	6.3±0.2	0.8±0.1	12.0±1.1	33.9±6.9	21.9±7.3
11.8±5.5	6.4±0.5	0.8±0.1	12.6±2.7	30.1±6.9	17.5±4.2
5.5±4.8	5.8±0.3	1.3±0.2	12.6±0.0	34.0±0.0	21.4±0.0
10.3±1.2	5.9±0.6	1.0±0.1	9.6±3.1	27.6±4.3	18.0±3.9
8.2±5.0	5.8±0.3	1.3±0.3	12.8±4.1	35.1±4.8	22.3±0.7
17.0±7.0	5.7±0.3	1.0±0.2	14.5±4.4	37.9±5.9	23.5±1.6
17.0±0.0	6.0±0.5	1.0±0.0	10.5±0.6	31.9±4.6	21.2±2.2
9.7±4.6	7.5±0.2	1.1±0.1	5.4±0.9	21.4±0.6	16.0±1.5
10.0±4.6	5.5±0.1	1.9±1.7	11.5±0.1	33.3±5.4	21.8±5.3
15.0±4.6	5.8±0.2	0.9±0.1	10.0±1.3	33.2±8.1	23.2±6.8
13.2±1.6	6.5±0.4	1.0±0.0			
13.5±4.7	6.0±0.5	1.1±0.3	11.2±2.7	31.7±6.5	20.6±4.2

Appendix II.2 (Continued).

Average Concentration of Organic Carbon(OC%), Average Horizon Thickness(HT)(cm), pH and Apparent Bulk Density(Db)($Mg \cdot m^{-3}$) in Cultivated and Native Profiles.

Horizon	OC	HT	pH	Db
Ap	2.7±0.8	14.0±5.3	6.1±0.7	1.2±0.2
B	1.9±0.4**	16.3±5.3	6.8±0.6	1.6±0.2
Ah	4.7±1.0	13.5±4.7	6.0±0.5	1.1±0.3
B	1.5±0.5	19.2±7.8	6.6±0.6	1.8±1.7

Appendix II.3 BLACK SAMPLING ZONE

Average concentration and mass of organic carbon in cultivated and native A horizons

Concentration of Organic Carbon(%)		Mass of Organic Carbon($kg \cdot ha^{-1}$)	
CULTIVATED	**NATIVE**	**CULTIVATED**	**NATIVE**
5.1±1.0	6.0±2.6	146 436±27 577	107 558±47 492
5.6±0.4*	9.0±2.7	112 126± 8 628	95 074±28 609
1.9±1.2**	6.0±1.1	34 667±22 935	48 280± 8 437
2.9±0.8**	6.5±0.3	29 532± 8 581	59 692± 3 083
6.5±0.2	7.9±1.4	59 108± 1 897	85 690±15 705
4.1±0.3**	6.2±0.8	176 536± 4 759	10 391±14 479
5.4±0.6**	7.3±1.2	122 014±12 769	116 647±19 142
3.4±0.8	4.2±1.1	64 010±14 117	96 214±19142
4.5±0.2*	14.2±4.1	92 318± 3 838	60 654±25 603
4.5±0.5**	10.7±1.7	71 714± 7 926	117 399±17 620
2.3±0.6**	4.9±0.8	375 988± 9 258	74 649±18 317
5.4±0.8	6.3±1.4	75 710±11 544	131 310±11 975
5.0±0.4	7.8±3.9	151 791±11 417	148 438±29 908
3.3±0.5*	5.6±1.5	92 678±12 489	161 081±74 415
2.7±0.0	2.9±0.0	78 013±00 000	79 487±42 609
4.2±1.4**	7.0±2.7	82 975±37 318**	99 504±32 682

Change in Concentration of OC(%)	Change in Mass of OC(%)
-15	+36
-37	+18
-69	-28
-55	-51
-18	-31
-34	-31
-26	+ 5
-19	-34
-68	+52
-58	-39
-54	-49
-13	-42
-35	+ 2
-41	-43
- 7	- 2

Appendix II.3 (Continued).

Average Mass and Change in Mass of Organic Carbon in Cultivated and Native Profiles

Mass of Organic Carbon($kg\cdot ha^{-1}$)		Change in Mass of Organic Carbon(%)
Cultivated	Native	
214 575± 34 924	152 457± 67 015	+41
156 254±113 343	206 817± 50 160	-24
34 667± 22 935	71 570± 8 385	-52
73 582± 24 924	109 244± 20 686	-33
122 670± 9 828	139 509± 33 184	-12
105 558± 13 234	157 489± 24 568	-33
170 925± 17 762	249 497± 91 279	-32
135 039± 21 867	171 041± 32 568	-21
116 175± 24 080	209 127± 33 540	-38
164 113± 25 882	193 610± 72 041	-15
58 167± 28 084	128 151± 10 815	-52
159 182± 53 143	190 493± 99 894	-16
199 571± 48 620	169 408± 71 922	+18
111 692± 11 904	206 884± 56 713	-46
78 013± 00 000	79 487± 00 000	- 2
127 837± 51 403**	162 319± 50 269	

Appendix II.3 (Continued).

Average Thickness(cm), pH, Apparent Bulk Density(Db)($\mathrm{Mg \cdot m^{-3}}$),Available Moisture Capacity(%)(AW), and Moisture Retention at -33 and -1500kPa(PW)(%)in Cultivated A Horizons

Thickness	pH	Db	AW	FC	PW
26.8±3.5	5.9±0.3	1.1±0.0	10.3±1.0	38.0±2.2	27.7±3.1
20.3±2.3	6.9±0.6*	1.0±0.1*	16.5±0.9	39.9±0.9	23.4±0.7
16.2±2.7	7.5±0.3**	1.2±0.1**	19.2±0.6	36.9±2.0	17.8±1.5
11.1±1.0	6.4±0.2*	0.9±0.1	15.7±1.8	37.4±1.9	21.8±4.5
10.3±0.6	5.7±0.2**	0.9±0.2	15.2±1.2	42.4±1.1	27.2±1.3
16.2±2.0	6.2±0.2	1.2±0.1	13.5±0.8	28.6±0.6	15.2±0.2
21.8±6.2	6.3±0.5	1.0±0.1	13.9±1.8	43.1±2.3	29.2±2.9
15.7±3.9	5.9±0.4	1.2±0.3	13.0±1.8	23.1±4.7	10.1±5.9
16.3±8.5	5.8±0.2	1.3±0.0	18.8±1.0	34.8±0.9*	16.0±0.1
18.8±5.3	7.5±0.3*	0.9±0.1**			
20.0±10.0	7.4±0.2**	1.2±1.3	13.0±1.0	33.9±4.7	21.0±3.7
13.8±2.9	6.0±0.4**	1.0±0.1*	15.5±1.5	36.5±1.3*	21.0±3.7
29.0±12.5	6.0±0.1	1.1±0.1*			
20.0±4.4	6.1±0.3	1.4±0.1**	13.2±1.6	27.4±1.0	14.2±0.7
18.3±5.3	6.4±0.6	1.1±0.2*	14.8±2.5**	36.2±6.1**	20.4±5.9**

Average Thickness(cm), pH, Apparent Bulk Density(Db)($\mathrm{Mg \cdot m^{-3}}$),Available Moisture Capacity(AW)(%), and Moisture Retention at -33(FC) and -1500kPa(PW) in Native A Horizons

Thickness	pH	Db	AW	FC	PW
17.3± 7.7	6.3±0.3	1.0±0.3	12.3±1.7	44.1±4.6	38.1±3.7
15.3± 8.4	6.0±0.5	0.6±0.2	15.0±0.0	41.1±0.0	26.1±0.0
11.2± 1.7	6.8±0.3	0.7±0.1	11.2±2.3	35.9±4.4	24.7±2.1
10.7± 1.5	6.1±0.2	0.8±0.1	14.2±0.7	40.9±6.0	26.8±5.3
15.3± 4.9	6.2±0.1	0.7±0.1	15.0±2.4	51.6±7.4	36.5±5.0
18.3± 5.0	6.1±0.2	1.0±0.1	6.7±0.9	28.3±10.0	21.6±9.7
17.3±11.3	6.4±0.2	0.8±0.3	11.5±0.8	47.6±3.6	36.1±4.2
24.8± 8.1	6.1±0.4	0.9±0.1	8.3±1.2	24.9±5.1	16.6±6.2
8.8± 1.3	5.8±0.7	0.5±0.2	13.5±2.3	38.2±1.7	24.7±0.6
16.8± 3.0	6.7±0.3	0.6±0.1			
16.0± 2.2	6.6±0.4	0.9±0.1	12.3±1.2	33.6±3.2	21.2 ±2.3
26.2±11.7	7.2±0.4	0.8±0.1	10.8±2.6	44.1±3.6	33.2 ±1.0
24.5±12.0	6.3±0.2	0.7±0.2			
26.7±18.1	5.9±0.6	1.1±.04	10.3±0.5	34.9±5.9	24.6±6.2
17.8± 5.8	6.4±0.4	0.8±0.2	11.8±2.6	38.8±7.7	27.0±6.2

Appendix II.3 (Continued).

Average Concentration of Organic Carbon(OC%), Average Horizon Thickness(HT)(cm), pH and Apparent Bulk Density(Db)($Mg\cdot m^{-3}$) in Cultivated and Native Profiles.

Horizon	OC	HT	pH	Db
Ap	4.2±1.4	18.3±5.3	6.4±0.6	1.1±0.6
B	2.0±1.3	17.2±5.2	6.8±0.7	1.4±0.3
Ah	7.0±2.7	17.8±5.8	6.4±0.4	0.8±0.2
B	2.2±1.6	20.2±7.1	6.7±0.5	1.3±0.1

Appendix II.4 DARK GRAY SAMPLING ZONE

Average concentration and mass of organic carbon in cultivated and native A horizons

Concentration of Organic Carbon(%)		Mass of Organic Carbon($kg \cdot ha^{-1}$)	
CULTIVATED	NATIVE	CULTIVATED	NATIVE
3.4 ±0.5	4.3 ±1.3	59 207± 8 706	93 227±27 295
3.2 ±0.9	3.3 ±0.3	67 108±20 068	83 854± 7 094
3.3 ±0.2	3.8 ±0.7	63 155± 5 590	88 540± 6 628

Change in Concentration of OC(%)	Change in Mass of OC(%)
-21	-37
- 4	-20

Average Mass and Change in Mass of Organic Carbon in Cultivated and Native Profiles

Mass of Organic Carbon($kg \cdot ha^{-1}$)		Change in Mass of Organic Carbon(%)
Cultivated	Native	
107 635±31 101	137 841±92 123	-22
90 542±14 357	117 528±12 133	-23
99 089±12 086*	127 684±14 363	

Appendix II.4 (Continued).

Average Thickness(cm), pH, Apparent Bulk Density(Db)(Mg·m^{-3}),Available Moisture Capacity(AW)(%), and Moisture Retention at -33 and -1500kPa(PW)(%) in Cultivated A Horizons

Thickness	pH	Db	AW	FC	PW
16.0±4.6	5.7±0.2*	1.1±0.1	16.9±1.3*	28.3±1.3	11.4±0.2
16.2±2.4**	6.3±0.4	1.3±0.1	17.5±1.1	30.5±2.7	13.1±1.7
16.0±0.1	6.0±0.4	1.2±0.2	17.2±0.4	29.4±1.6	12.3±1.2

Average Thickness(cm), pH, Apparent Bulk Density(Db)(Mg·m^{-3},Available Moisture Capacity(AW)(%), and Moisture Retention at -33 and -1500kPa(PW)(%) in Native A Horizons

Thickness	pH	Db	AW	FC	PW
19.2±6.6	6.1±.3	1.1±.2	11.8±2.0	28.3±5.1	16.5±6.7
22.3±1.2	6.8±.4	1.1±.2	15.9±0.8	30.6±1.2	14.7±1.3
21.0±2.2	6.4±.5	1.1±.03	13.9±2.9	29.5±1.6	15.6±1.3

Appendix II.4 (Continued).

Average Concentration of Organic Carbon(OC%), Average Horizon Thickness(HT)(cm), pH and Apparent Bulk Density(Db)($Mg\cdot m^{-3}$) in Cultivated and Native Profiles.

Horizon	OC	HT	pH	Db
Ap	3.3±0.2	16.0±0.1	6.0±0.4	1.2±0.2
Ae	0.8±0.0	4.5±0.0	6.4±0.0	2.2±0.0
B	1.0±0.6	25.3±2.5	6.6±0.4	1.3±0.1
Ah	3.8±0.7	21.0±2.2	6.4±0.5	1.1±0.0
Ae	1.0±0.0	8.0±0.0	6.4±0.0	1.6±0.0
B	0.6±0.1	20.4±2.7	7.1±0.3	1.5±0.1

Appendix II.5 GRAY LUVISOLIC SAMPLING ZONE

Average concentration and mass of organic carbon in cultivated and native A horizons

Concentration of Organic Carbon(%)		Mass of Organic Carbon(kg ha^{-1})	
CULTIVATED	NATIVE	CULTIVATED	NATIVE
3.6±0.3	7.5±3.5	57 514± 5 418	48 990±22 845
1.9±0.7*	10.0±5.5	54 584±20 441	28 523±15 784
2.4±0.4**	12.0±4.2	58 419±10 983	82 731±29 068
2.3±0.3	5.7±3.0	46 117± 7 187	144 608±75 607
2.3±0.4*	13.9±8.5	58 340± 9 262	106 991±65 593
2.3±0.2*	14.3±7.3	39 703± 3 598	50 323±25 709
1.2±0.1**	1.5±0.1	35 184± 1 554	19 885± 1 958
2.3±0.7**	9.3±4.7	49 980±9 648	68 787±44 845

Change in Concentration of OC(%)	Change in Mass of OC(%)
-52	+17
-81	+91
-80	-29
-59	-68
-83	-45
-84	-21
-19	+77

Aggregation at the zone level:
mean mass change for the zone=(49 980 - 68 787)/68 787=-27%

Aggregation at the farm level:
mean mass change for the zone=(+17+91-29-68-45-21+77)/7=+3%

Aggregation at the profile level:
mean mass change for the zone=(+44+201-21-62-4.5+7+78)/7=+35%

Appendix II.5 (Continued).
Average Mass and Change in Mass of Organic Carbon in Cultivated and Native Profiles

Mass of Organic Carbon(kg ha^{-1})		Change in Mass of Organic Carbon(%)
Cultivated	Native	
73 085±10 314	73 564± 29 091	-0.6
75 896±25 192	96 994± 17 372	-22
70 118±12 425	97 752± 34 168	-28
61 510±10 368	16 833± 76 269	-63
77 091±12 740	173 652±103 036	-56
57 274± 2 096	107 360± 46 665	-47
47 848± 3 861	41 202± 5 552	+16
66 117±10 907*	108 409± 48 000	

Appendix II.5 (Continued).

Average Thickness(cm), pH, Apparent Bulk Density(Db)($Mg\cdot m^{-3}$),Available Moisture Capacity(AW)(%), and Moisture Retention at -33 and -1500kPa(PW)(%) in Cultivated A Horizons

Thickness	pH	Db	AW	FC	PW
12.7±2.0	6.1±0.1**	1.3±0.1**	18.4±0.4**	30.3±0.8	11.8±0.3**
20.3±2.5**	6.0±0.5	1.4±0.1**	15.5±0.4	25.0±0.9	
18.0±1.5**	6.8±0.2	1.3±0.1	13.3±0.4	20.3±1.4	
15.3±0.6	6.1±0.2	1.3±0.1	14.5±1.3	24.5±0.3	10.0±1.5
17.7±5.7	6.4±0.3	1.4±0.1*	16.7±0.7	26.5±2.3	9.6±3.0
14.2±1.2**	7.4±0.2	1.2±0.2**	11.7±1.9	18.7±2.0	7.0±0.6
19.0±2.0**	6.2±0.2*	1.5±0.2	18.6±1.5	23.8±1.9	5.2±0.4*
16.7±2.7	6.4±0.5	1.3±0.1**	15.5±2.9	24.7±4.2	8.7±2.6

Average Thickness(cm), pH, Apparent Bulk Density(Db)($Mg\ m^{-3}$),Available Moisture Capacity(AW)(%), and Moisture Retention at -33 and -1500kPa(PW)(%) in Native A Horizons

Thickness	pH	Db	AW	FC	PW
9.3±4.2	5.6±0.2	0.7±0.1	11.0±0.0	29.7± 0.0	18.7± 0.0
5.3±2.8	6.0±0.0	0.6±0.2			
5.5±2.8	6.3±0.8	1.4±0.9			
23.3±8.4	6.2±0.2	1.0±0.3	11.6±1.2	43.7±21.4	32.1±22.6
10.2±6.5	6.0±0.5	0.6±0.4	9.7±2.9	31.7±15.8	22.0±12.8
5.8±2.0	7.2±0.0	0.6±0.1	9.0±0.9	19.6± 4.3	11.6± 3.5
12.0±0.5	5.8±0.2	1.1±0.1	19.6±2.7	26.1± 2.4	6.4± 0.5
10.2±6.3	6.2±0.5	0.8±0.3	12.2±4.3	30.1± 8.9	18.0±10.0

Appendix II.5 (Continued).

Average Concentration of Organic Carbon(OC%), Average Horizon Thickness(HT)(cm), pH and Apparent Bulk Density(Db)($Mg \cdot m^{-3}$) in Cultivated and Native Profiles.

Horizon	OC	HT	pH	Db
Ap	2.3±0.7	16.7±2.7	6.4±0.5	1.3±0.1
Ae	0.5±0.3	15.2±16.6	6.7±0.5	1.3±0.2
B	0.5±0.1	16.8±4.4	6.2±0.5	1.6±0.1
LFH/Ah	9.3±4.7	10.2±6.3	6.2±0.5	0.8±0.3
Ae	0.8±0.4	14.2±8.7	6.3±0.5	1.7±0.7
B	0.6±0.2	15.1±5.1	6.1±0.6	1.6±0.1

Appendix II.6 PEACE RIVER SAMPLING ZONE

Average concentration and mass of organic carbon in cultivated and native A horizons

Concentration of Organic Carbon(%)		Mass of Organic Carbon($kg \cdot ha^{-1}$)	
CULTIVATED	NATIVE	CULTIVATED	NATIVE
3.9±0.2	4.3±0.5	61 963± 2 857	65 098± 7 336
2.3±0.1**	5.1±1.6	43 134± 2 895	68 999±22 333
1.5±0.6*	18.7±10	43 800±18 566	39 735±22 703
1.7±0.7**	20.5±5.8	34 540±14 179	42 306±11 985
3.2±0.5*	5.9±1.5	54 349± 8 904	76 871±20 312
2.5±0.2**	6.6±0.6	38 512± 2 511	71 494± 7 088
4.1±0.9**	7.2±0.6	111 705±25 321	106 830± 8 393
3.1±0.1	2.6±0.8	90 992± 1 629	19 166± 5 846
3.9±0.3**	7.3±1.8	40 778± 3 048	142 095±35 789
1.8±0.7	5.0±2.5	28 759±10 538	17 829± 8 803
3.7±0.5**	8.0±0.9	65 471± 8 267	131 083±15 251
4.5±0.0	8.1±2.4	93 893±00 000	65 772±19 633
3.0±1.0**	8.3±5.5	58 991±26 694	70 606±39 729

Change in Concentration of OC(%)	Change in Mass of OC(%)
- 9	- 5
-56	-38
-92	+10
-91	-18
-47	-29
-62	-46
-44	+ 5
+20	
-46	-71
-64	+61
-53	-50
-44	+43

Appendix II.6 (Continued).

Average Mass and Change in Mass of Organic Carbon in Cultivated and Native Profiles

Mass of Organic Carbon($kg.ha^{-1}$)		Change in Mass of Organic Carbon(%)
Cultivated	Native	
112 435± 3 680	149 748±11 560	-25
55 095± 3 140	86 945±15 064	-37
80 135±27 446	78 293±24 335	+ 2
47 785±21 129	80 866±22 135	-41
98 379±31 957	144 972±41 479	-32
64 975±15 319	249 443±29 599	-74
131 677±29 406	131 553± 6 245	+.1
112 866± 5 728	38 826±21 958	+191
102 572± 8 477	194 111±35 717	-47
46 290±17 176	40 218±14 407	+15
118 996±37 957	189 054±21 251	-37
144 467±00 000	158 608±38 711	- 9
92 973±33 476	128 553±65 079	

Appendix II.6 (Continued).

Average Thickness(cm), pH, Apparent Bulk Density(Db)(Mg·m⁻³),Available Moisture Capacity(AW)(%), and Moisture Retention at -33 and -1500kPa(PW)(%)in Cultivated A Horizons

Thickness	pH	Db	AW	FC	PW
13.3±1.2	6.2±0.2**	1.2±0.1	14.3±0.8*	37.6±1.2	23.3±0.6**
14.3±1.2	6.2±0.2**	1.3±0.1**	18.0±1.6	26.8±1.7**	8.8±0.7
23.0±4.6**	6.6±0.2	1.3±0.0*	17.6±3.0	27.0±2.5	9.4±2.9
12.7±5.5	6.9±0.5	1.4±0.2**	18.1±1.1	24.7±1.4	
14.8±4.2	6.0±0.5	1.2±0.2	16.9±1.6	32.8±1.6	15.9±2.8
14.3±6.0	5.8±0.2	1.2±0.6	14.9±0.3	32.3±0.1*	17.7±0.4*
14.2±1.6	5.9±0.7	2.0±1.6	16.4±5.2	34.8±5.9**	18.3±2.9**
11.0±1.7	5.6±0.1*	2.5±2.3	15.4±1.3	33.7±0.6*	18.3±1.9*
13.2±3.0	6.1±0.2	0.8±0.1**	18.3±3.5	33.3±3.1*	15.0±0.4
10.0±0.0**	6.3±0.5	1.6±0.6	16.9±4.1	32.6±0.8	15.7±3.8
15.5±5.8	6.5±0.1	1.1±0.1**	12.3±0.6	33.0±1.4**	20.7±2.0**
17.0±0.0	5.4±0.0	1.2±0.0	16.5±0.0	41.0±0.0	00.0±0.0
14.5±3.3	6.1±0.4	1.4±0.5**	16.3±1.8	33.2±4.0**	17.1±4.9

Average Thickness(cm), pH, Apparent Bulk Density(Db)(Mg·m⁻³),Available Moisture Capacity(%)(AW), and Moisture Retention at -33 and -1500kPa(PW)(%) in Cultivated A Horizons

Thickness	pH	Db	AW	FC	PW
13.0±1.7	5.9±0.0	1.2±0.1	12.1±1.1	39.3±1.8	27.1±0.9
17.2±2.3	5.6±0.0	0.8±0.0	19.6±2.5	37.0±3.7	17.4±6.1
4.5±1.8	6.3±1.2	0.4±0.2	12.4±0.0	32.1±0.0	19.7±0.0
6.8±1.6	6.1±0.0	0.3±0.1			
13.7±1.2	6.4±0.1	0.9±0.1	12.9±2.7	36.1±10.5	23.2±8.0
14.8±4.3	5.9±0.0	0.7±0.1	14.5±0.5	38.9±2.1	24.4±2.3
16.3±4.0	5.8±0.1	0.9±0.1	15.1±1.6	44.7±1.2	29.6±2.6
7.2±0.3	7.1±0.0	1.1±0.0	15.1±1.6	38.3±2.0	23.2±0.4
15.8±5.9	6.1±0.0	1.3±0.0	18.0±3.7	46.2±4.8	28.2±8.2
5.2±0.1	6.1±0.1	0.7±0.0	20.1±7.3	42.4±7.7	22.3±3.6
21.0±7.0	6.2±0.0	0.8±0.0	10.6±2.4	44.6±3.3	34.0±4.0
7.5±4.3	5.7±0.0	1.3±0.1	20.7±3.2	48.5±6.6	27.8±3.4
11.9±5.4	6.1±0.4	0.9±0.3	15.6±3.5	40.7±4.9	25.2±4.7

Appendix II.6 (Continued).

Average Concentration of Organic Carbon(OC%), Average Horizon Thickness(HT)(cm), pH and Apparent Bulk Density(Db)($Mg \cdot m^{-3}$) in Cultivated and Native Profiles.

Horizon	OC	HT	pH	Db
Ap	3.0±1.0	14.5±3.3	6.1±0.4	1.4±0.5
Ae	1.0±0.4	9.6±4.2	6.2±0.3	1.5±0.3
B	1.3±0.8	20.4±9.1	6.4±0.4	1.4±0.2
Ah(LFH)	8.3±5.5	11.9±5.4	6.1±0.4	0.9±0.3
Ae	1.3±0.3	10.4±3.2	6.1±0.4	1.4±0.2
B	1.2±0.5	18.8±9.9	6.3±0.5	1.4±0.3

9. APPENDIX III

Results from Simple Linear Regression Analyses

Appendix III.1: Statistics for Simple Linear Regression Analysis: Present Concentration of Organic Carbon with Cultivation Time

Soil Zone	r	Signif.	Y-Int.	Slope	N
BR	-.27	.21	1.57	-.003	11
DB	+.12	.33	2.31	+.005	16
BL	-.37	.10	5.93	-.030	14
DG					2
GL	-.50	.13	2.3	-.020	7
PR	+.52	.08	1.7	+.030	9
PROV	+.21	.06	2.19	+.010	59

Appendix III.2: Statistics for Simple Linear Regression Analysis: Change in Concentration of Organic Carbon with Cultivation Time

Soil Zone	r	Signif.	Y-Int.	Slope	N
BR	-.56	.04	-28.2	-.5	11
DB	+.16	.27	-50.8	.1	16
BL	-.05	.43	-35.6	-.1	14
DG					2
GL	+.18	.35	-73.8	.2	7
PR	+.49	.09	-87.9	.9	9
PROV	+.14	.15	-52.2	.15	59

For abbreviations see Appendix III.3

Appendix III.3: Statistics for Simple Linear Regression Analysis: Change in Mass of Organic Carbon with Cultivation Time

Soil Zone	r	Signif.	Y-Int.	Slope	N
BR	-.11	.38	-15.5	-0.15	10
DB	+.07	.40	-33.3	+0.09	16
BL	-.14	.30	-32.4	+0.23	14
DG					2
GL	+.58	.08	-63.7	+1.70	7
PR	-.50	.10	51.9	-1.10	8
PROV	-.03	.42	-14.4	-0.05	57

BR: Brown Sampling Zone
DB: Dark Brown Sampling Zone
BL: Black Sampling Zone
DG: Dark Gray Sampling Zone
GL: Gray Luvisolic Sampling Zone
PR: Peace River Sampling Zone
PROV: Province

r: correlation coefficient
Signif.: Significance
Y-Int.: Intercept with Y-axis
N: number of cases

Appendix III.4: Simple Linear Regression Analysis for the PROVINCE: Influence of Management Practices(1982-1967) on the Relationship Between Present Concentration of Organic Carbon(1), Change in Concentration of Organic Carbon(2) and Change in Mass of Organic Carbon(3) with Cultivation Time. .

Management practice	DV	r	Sign.	Y-Int.	Slope	N
Summerfallow	1	+.26	.08	+ 1.6	+0.02	30
	2	+.03	.43	-50.4	+0.03	29
	3	-.24	.10	+ 4.4	-0.42	30
Continuous cropping	1	+.36	.03	+ 2.3	+0.02	26
	2	+.36	.03	-58.2	+0.43	26
	3	+.10	.32	-24.4	+0.12	24
Lay farming	1	-.40	.37	+ 6.7	-0.06	3
	2	-.59	.30	+50.8	-1.70	3
	3	+.88	.15	-347.	+ 6.20	3
Straw removed	1	+.89	.01	+ 0.9	+0.04	6
	2	+.90	.01	-126.	+1.28	6
	3	+.50	.14	-40.1	+0.40	6
Stubble mulch	1	+.21	.11	+ 2.0	+0.10	34
	2	+.03	.43	-45.6	+0.03	33
	3	-.12	.24	- 7.8	-0.20	34
Manure	1	-.50	.20	+ 7.1	-0.05	5
	2	-.69	.15	+75.4	-2.03	4
	3	+.20	.40	-41.5	+0.82	5
All straw Returned	1	+.00	.49	+ 3.8	+0.00	10
	2	+.14	.35	-39.2	+0.13	10
	3	+.26	.23	-37.5	+0.39	10

DV: dependant variable. 1=present concentration of organic carbon; 2=change in concentration of organic carbon
3=change in mass of organic carbon
r: correlation coefficient; Sign.: significance;
Y-Int.: Intercept with Y-axis; N: number of cases

Appendix III.5: Simple Linear Regression Analysis for the BROWN SAMPLING ZONE: Influence of Management Practices(1982-1967) on the Relationship Between Present Concentration of Organic Carbon(1), Change in Concentration of Organic Carbon(2) and Change in Mass of Organic Carbon(3) with Cultivation Time.

Management practice	DV	r	Sign.	Y-Int.	Slope	N
Summerfallow	1	-.43	.14	+ 1.60	+.00	8
	2	-.56	.07	- 0.29	-.48	8
	3	-.27	.25	+ 2.50	-.45	8
Continuous cropping	1	+.13	.46	+ 1.40	+.01	3
	2	-.14	.46	-27.30	-.55	3
	3					2
Stubble mulch	1	-.29	.22	+ 1.60	-.00	9
	2	-.55	.06	-27.50	-.54	9
	3	-.64	.04	- 0.46	-.72	8

DV: dependant variable 1=present concentration of organic carbon; 2=change in concentration of organic carbon 3=change in mass of organic carbon

r: correlation coefficient; Sign.: significance;

Y-Int.: Intercept with Y-axis; N: number of cases

Appendix III.6: Simple Linear Regression Analysis for the DARK BROWN SAMPLING ZONE: Influence of Management Practices(1982-1967) on the Relationship Between Present Concentration of Organic Carbon(1), Change in Concentration of Organic Carbon(2) and Change in Mass of Organic Carbon(3) with Cultivation Time.

Management practice	DV	r	Sign.	Y-Int.	Slope	N
Summerfallow	1	+.09	.40	+ 2.4	+.00	11
	2	+.21	.30	-54.5	+.18	11
	3	+.21	.30	-43.6	+.17	11
Continuous cropping	1	+.26	.30	+ 1.8	+.01	5
	2	-.30	.30	-27.7	-.19	5
	3	-.30	.30	31.0	-.72	5
Straw removed	1	+.98	.06	- 0.9	+.07	3
	2	+.53	.32	-63.8	+.34	3
	3	+.99	.02	-67.7	+.93	3
Stubble mulch	1	+.12	.36	+ 2.2	+.10	11
	2	+.14	.34	-49.4	+.12	11
	3	+.10	.38	-34.6	+.11	11

DV: dependant variable 1=present concentration of organic carbon; 2=change in concentration of organic carbon
3=change in mass of organic carbon
r: correlation coefficient; Sign.: significance;
Y-Int.: Intercept with Y-axis; N: number of cases

Appendix III.7: Simple Linear Regression Analysis for the BLACK SAMPLING ZONE: Influence of Management Practices(1982-1967) on the Relationship Between Present Concentration of Organic Carbon(1), Change in Concentration of Organic Carbon(2) and Change in Mass of Organic Carbon(3) with Cultivation Time.

Management practice	DV	r	Sign.	Y-Int.	Slope	N
Summerfallow	1	+.54	.30	- 9.1	+0.20	4
	2	+.28	.40	-129.	+0.96	3
	3	+.85	.07	-393.	+4.80	4
Continuous cropping	1	-.23	.30	+ 5.4	-0.01	9
	2	+.38	.16	-55.1	+0.40	9
	3	+.33	.19	-45.1	+0.50	9
Stubble mulch	1	-.48	.16	+ 5.6	-0.03	6
	2	+.14	.41	-61.9	+0.11	5
	3	-.00	.49	-21.8	+0.00	6
All straw Returned	1	+.02	.48	+ 4.9	+0.00	5
	2	-.27	.33	-19.4	-0.17	5
	3	+.73	.07	-77.6	+0.90	5

DV: dependant variable 1=present concentration of organic carbon; 2=change in concentration of organic carbon
3=change in mass of organic carbon

r: correlation coefficient; Sign.: significance;
Y-Int.: Intercept with Y-axis; N: number of cases

Appendix III.8: Simple Linear Regression Analysis for the GRAY LUVISOLIC SAMPLING ZONE: Influence of Management Practices(1982-1967) on the Relationship Between Present Concentration of Organic Carbon(1), Change in Concentration of Organic Carbon(2) and Change in Mass of Organic Carbon(3) with Cultivation Time.

Management practice	DV	r	Sign.	Y-Int.	Slope	N
Summerfallow	1	-.98	.05	+ 5.6	-0.09	3
	2	+.65	.27	-105.	+1.40	3
	3	+.68	.26	-77.2	+2.60	3

Only 1 or 2 cases per management group;

Appendix III.9: Simple Linear Regression Analysis for the PEACE RIVER SAMPLING ZONE: Influence of Management Practices(1982-1967) on the Relationship Between Present Concentration of Organic Carbon(1), Change in Concentration of Organic Carbon(2) and Change in Mass of Organic Carbon(3) with Cultivation Time.

Management practice	DV	r	Sign.	Y-Int.	Slope	N
Summerfallow	1	+.83	.08	+ 0.50	+0.05	4
	2	+.98	.01	-80.00	+0.50	4
	3	-.70	.14	+107.3	-2.00	4
Continuous cropping	1	+.36	.28	+ 2.09	+0.02	5
	2	+.68	.10	-108.4	+1.60	5
	3	-.36	.32	+32.80	-0.83	4
Stubble mulch	1	+.26	.31	+ 2.43	+0.02	6
	2	+.34	.26	-71.00	+0.70	6
	3	-.49	.20	+80.40	-1.50	5

DV: dependant variable 1=present concentration of organic carbon; 2=change in concentration of organic carbon
3=change in mass of organic carbon
r: correlation coefficient; Sign.: significance;
Y-Int.: Intercept with Y-axis; N: number of cases